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MISCELLANEOUS CONTRIBUTIONS TO OCEANOGRAPHY AND MARINE BIOLOGY

Cape Town

1967

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MISCELLANEOUS CONTRIBUTIONS TO OCEANOGRAPHY AND MARINE BIOLOGY

Published in 1967 by the Division of Sea Fisheries, Beach Road, Sea Point, Cape Town

This report is a continuation of the series of Fisheries Bulletins last published in 1951, and includes miscellaneous contributions of general rather than specific interest

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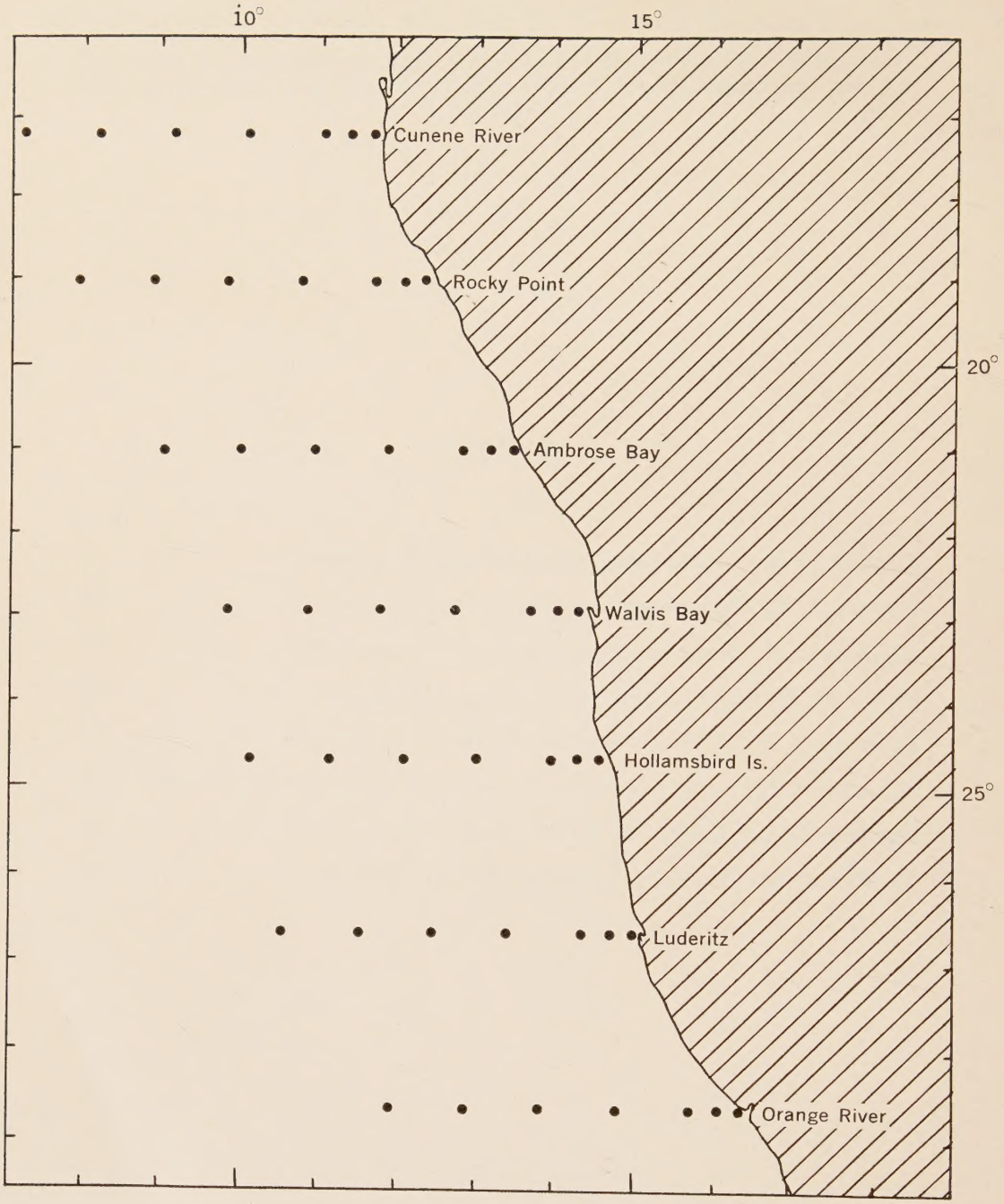

FIG. 1. POSITION OF STATIONS IN AREA INVESTIGATED.

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THE BENGUELA CURRENT OFF SOUTH WEST AFRICA*

G. H. Stander

INTRODUCTION

The year 1949 marked the birth of the pelagic fishery of South West Africa. During the following fifteen years the landings of pilchards soared from a figure of 8,771 tons to reach a total of 720,000 tons in 1964. The value of marine products produced in the Territory of South West Africa during the latter year attained a new record figure of almost R30,000,000. The future of the fishing industry seems bright, especially in view of the fact that there are still numerous unexploited resources. These include tuna, shrimps, possibly anchovies and further developments in the whitefish industry. Evidence also suggests that vast shoals of maasbankers occur in the northern waters of the Territory.

The coast of South West Africa is influenced by the cold Benguela Current. The conditions that exist along this coast are in many ways analogous to what is encountered in other west coast regions, namely, off California, Peru and Western Australia. The high productivity of these regions is closely related to upwelling, a process by which cold, nutrient-rich sub-surface water is elevated to the surface, that is, to the euphotic zone where it supports the growth of phytoplankton, the first link in the food cycle of the sea. From the foregoing it will be clear that a study of the physical and chemical conditions within the current will cast much light on the productivity of the coastal waters.

The South West Africa Administration established a marine research laboratory in 1950, but for many years progress was seriously hampered by lack of suitably qualified staff. Investigational work gained momentum with the inauguration of the Integrated Pilchard Research Programme (in conjunction with the Division of Sea Fisheries) in 1959 and since that year steady progress has been maintained. Various research vessels have visited South West African waters since World War II, for example, the R.V. *Crawford*, R.V. *Atlantis*, R.V. *Muksun* and R.R.S. *William Scoresby*, but undoubtedly the most comprehensive survey ever made of the region was undertaken by R.S. *Africana II* and R.V. *Sardinops* during the years 1959—1961. The present report is a brief summary of some of the findings made in the course of these investigations.

*The South African Shipping News XX (4): 105—111, April 1965.

SCOPE OF THE INVESTIGATION

In the original research programme of the Division of Sea Fisheries, provision was made for seven lines of research stations running westwards from the coast, namely, at the Orange River, Lüderitz, Hollam's Bird Island, Pelican Point, Ambrose Bay, Rocky Point and Cunene River (Fig. 1). Each line was to consist of seven stations, situated at distances of 5, 21, 45, 95, 145, 195 and 250 miles off shore and the aim was to repeat the survey four times per annum, coincident with the middle month of each season. On account of various practical difficulties, the programme had to be severely curtailed after about a year, and other commitments in Republic waters eventually compelled the Division to abandon further work in S.W.A. waters. Nevertheless nine surveys were completed, which involved a total of about 370 stations and entailed steaming approximately 18,000 miles. At each station plankton collections were made and water samples were collected to depths of up to *circa* 1,750 metres for the measurement of temperature, salinity and dissolved oxygen.

THE SOUTH WEST AFRICAN COAST

Apart from a few minor indentations the South West African coastline is straight and featureless and runs in a north-north-westerly direction.

Compared with the south and east coasts of South Africa the bottom topography of this region also exhibits few noteworthy features. A very broad underwater promontory is encountered off the Orange River, which is shown vividly by the 100 and 200 fathom isobaths (Fig. 2). Farther north the continental shelf narrows and once again broadens out in the Walvis region. As the Cunene River is approached the shelf becomes progressively narrower. In the Rocky Point region the 1,000 fathom isobath shows the junction between the Walvis Ridge (which extends westwards to the Mid-Atlantic Ridge) and the mainland.

The wind pattern along the coast of South West Africa varies with the distance off shore. Near the coast the wind direction depends on the relation between the continental and oceanic pressure systems. As a result of this there is a well-defined diurnal pattern which is subject to a certain degree of seasonal variation. Southerly to south-westerly

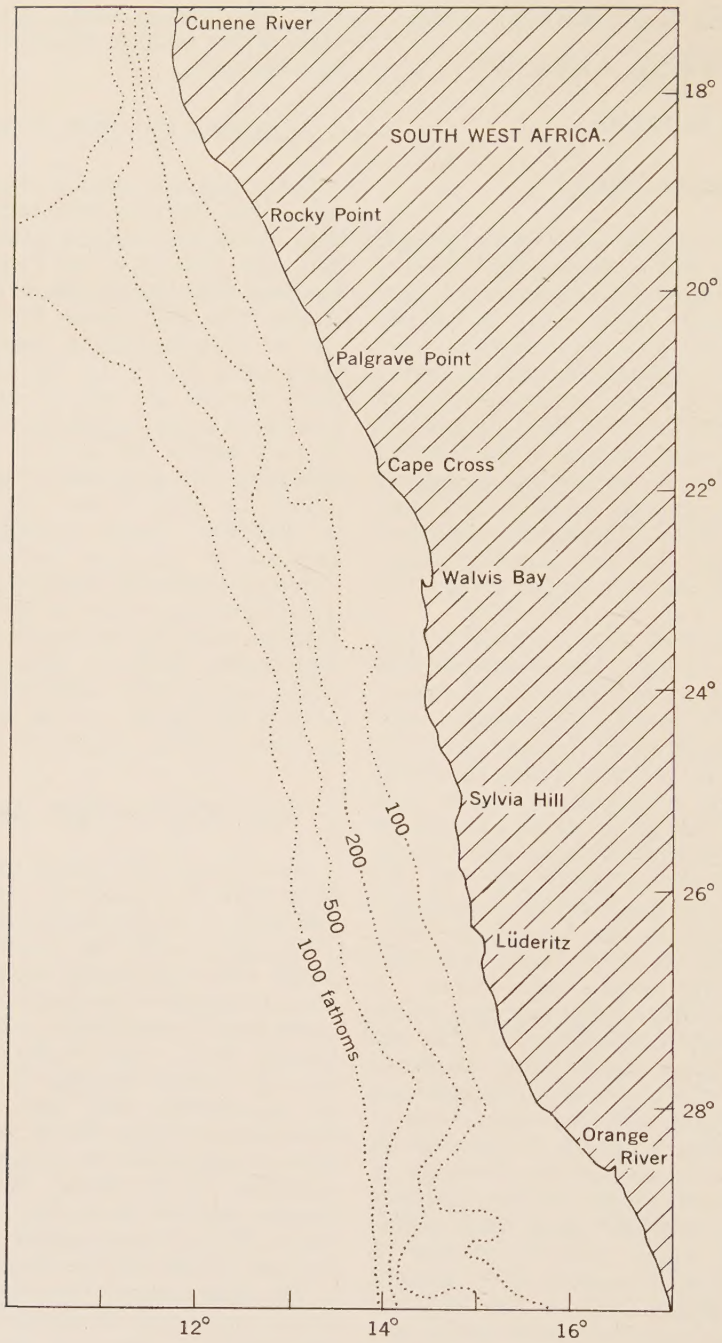

FIG. 2. BOTTOM TOPOGRAPHY OF THE S.W. AFRICAN COAST.

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winds are more or less dominant throughout the year, with easterly winds and northerly winds prevalent during winter and summer respectively. The winds farther off shore are much more consistent, for example at a distance of 250 miles off shore 80 per cent of all winds recorded were within an arc of 30°, while 40 miles off shore the corresponding figure was 44 per cent. The mean direction of the wind within 40 miles of the coast was *circa* 180°, that is southerly, and 250 miles off the coast it was *circa* 153°, that is south-south-easterly. Farther off shore the south-east trade wind is encountered. It will be shown below that, as in the case of the wind, the in-shore currents are variable compared with the off-shore currents.

TEMPERATURE AND SALINITY DISTRIBUTION

The surface distribution of temperature showed marked variations according to locality and season. Cold water was found in shore and warmer water off shore, temperature gradients being pronounced in summer and autumn and relatively weak during the remainder of the year. The coldest water was normally encountered in the Lüderitz locality and the warmest water west of the Cunene River.

In the case of salinity (expressed as parts per thousand, $^{\circ}/_{\circ\circ}$) distribution the surface isohalines were more or less parallel to the coast in the south, being deflected sharply towards the shore north of Walvis Bay. Due to this pattern low salinities (less than $35{\cdot}0^{\circ}/_{\circ\circ}$) were normally found in shore south of Walvis Bay, with values increasing rapidly to $35{\cdot}7$—$35{\cdot}9^{\circ}/_{\circ\circ}$ in the latitude of the Cunene River.

The tendencies described above were also more or less valid for the 100 metres layer. At greater depths (200—400 metres) conditions were widely divergent from those described for the upper layers. The most outstanding feature here was a wedge of relatively warm, highly saline water near the coast, separated from the off-shore waters by cooler, less saline water. This phenomenon was most conspicuous in the region north of *circa* 23° S, but was periodically evidenced much farther south. The conclusion reached by Hart and Currie* during the 1950 expedition of R.R.S. *William Scoresby* that in this particular region a southward-setting current flows beneath the Benguela Current, does not seem unreasonable.

*HART, T. J. and CURRIE, R. I. (1960): *Discovery Rep.* XXXI: 123—298.

WATER MASSES

The surface waters encountered in the area investigated varied between cold upwelled water of temperatures between 10° and 14° C and salinities between $34{\cdot}7$ and $35{\cdot}0^{\circ}/_{\circ\circ}$ and warm subtropical Atlantic surface water of temperatures between 16° and 22° C and salinities reaching values up to $35{\cdot}9^{\circ}/_{\circ\circ}$.

The fact that few observations were made in depths exceeding *circa* 1,500 metres limits the discussion of deep water masses. Temperature/salinity curves constructed showed the pattern characteristic of the South Atlantic Ocean, namely, a straight line piece representing the Atlantic Central Water, a salinity minimum representing the core of the Antarctic Intermediate Water and a further straight line piece showing the upper layers of the Warm Deep Layer (Fig. 3). The curves for various latitudes, however, showed a certain degree of divergence. It was, for instance, found that while upper portions of the curves for latitudes 29° S and 23° S agreed fairly closely the corresponding curve for 17° S showed that at any particular temperature the waters in the north had a higher salinity than farther south. The core values of the Antarctic Intermediate Water also varied according to latitude. Core temperatures fluctuated between $4{\cdot}4^{\circ}$ and $4{\cdot}5^{\circ}$ C, but salinities increased with decreasing latitude, for example, $34{\cdot}35^{\circ}/_{\circ\circ}$ off the Orange River, $34{\cdot}39^{\circ}/_{\circ\circ}$ off Walvis Bay and $34{\cdot}49^{\circ}/_{\circ\circ}$ off the Cunene River.

The Antarctic Intermediate Water which is formed in the region of the Antarctic Convergence flows northwards (at *circa* 600—800 metres) and in the process mixes with the waters above and below it. On the South West African coast only 40 to 50 per cent of the original water type is still present at the core, lying at 600 to 800 metres.

DISSOLVED OXYGEN

A study of the dissolved oxygen at the 200 and 400 metre levels disclosed interesting facts. The patterns at these two depths show close agreement in general.

The horizontal distribution was characterised by well-aerated water (4—5 c.c./l.O_2) in the south-west of the survey area and poorly aerated water in the north-east (sometimes less than 0·5 c.c./l.). In most cases, especially at 200 metres, the transition between the two types of water was rapid. Increases of up to $3\frac{1}{2}$ c.c./l. over about 50 miles were not uncommon. The low oxygen water is a continuation of the oxygen minimum layer found in

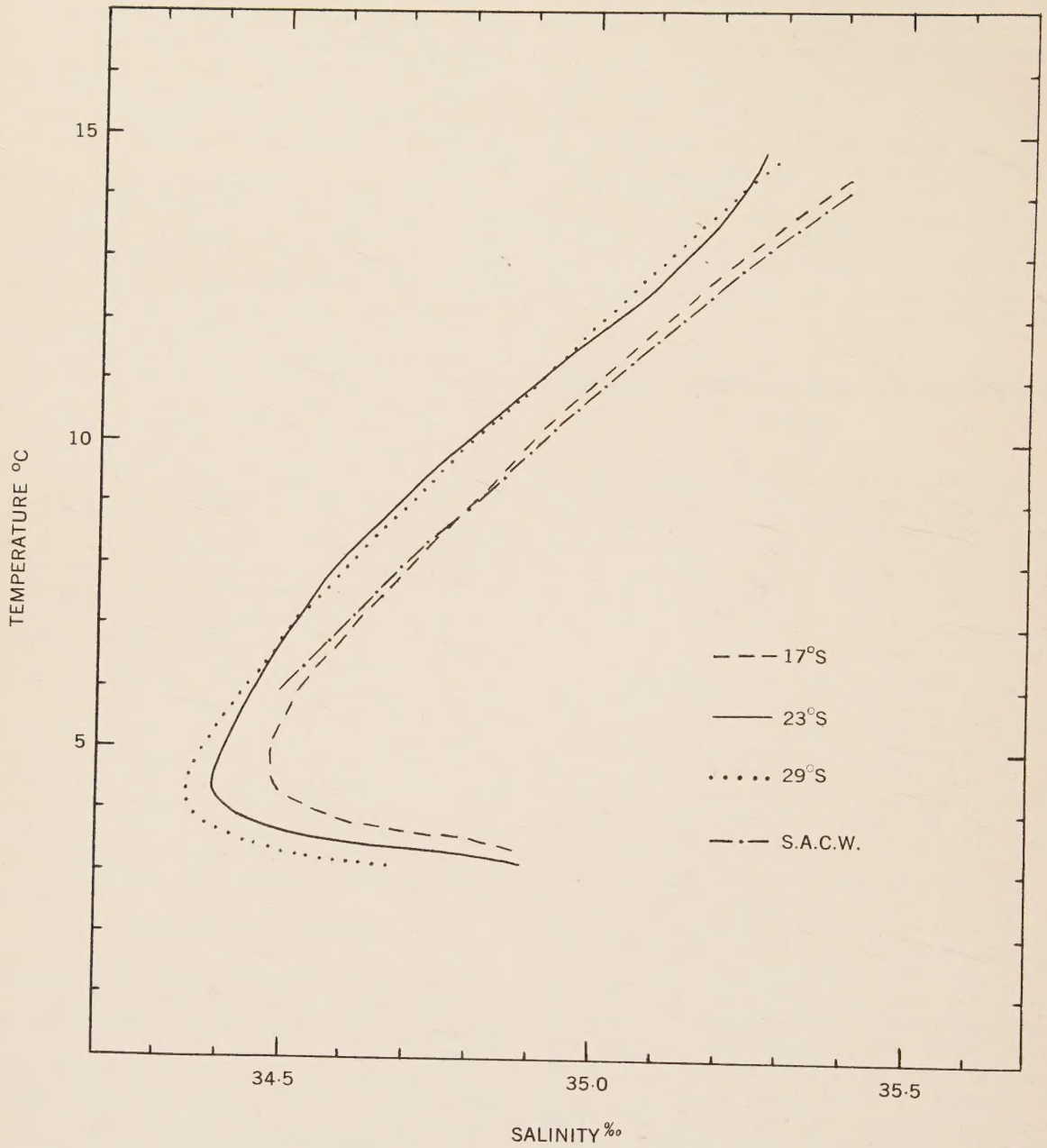

FIG. 3 MEAN TEMPERATURE/ SALINITY VALUES FOR THREE LOCALITIES ON THE WEST COAST OF SOUTH AFRICA (S.A.C.W. = SOUTH ATLANTIC CENTRAL WATER)

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equatorial regions of the South Atlantic Ocean and its presence lends support to the concept of a southward-setting current at sub-surface depths.

A comparison was made between the temperature/oxygen relationships of waters from different latitudes. The diagram for lower latitudes showed a marked oxygen minimum. At 17° S the oxygen minimum (less than 0·5 c.c./l.) corresponded to a temperature of 9°—10° C. Below 8° C the oxygen content of the water increased sharply and below 4° C volumes between 4 and 5 c.c./l. had been attained. The oxygen minimum was especially marked to the north of Hollam's Bird Island. By way of comparison it may be mentioned that a few stations in latitudes 32° to 34° S showed almost constant oxygen contents of 4 to 5 c.c./l. in the temperature range of 4° to 15° C. It may also be stated that the layer of water of less than 1 c.c./l. oxygen sometimes attained a thickness of 300 metres near the coast (see Fig. 4).

At depths exceeding 400 metres the following ranges of oxygen content were found:—

600 m. : 1·30—6·20 c.c./l.
800 m. : 1·83—5·50 c.c./l.
1,000 m. : 2·81—5·26 c.c./l.

It will be noticed that the deeper layers were again all well aerated.

WATER MOVEMENTS

There is scant information about the flow of the Benguela Current off the South West African coast. The low-lying coastline, the absence of landmarks and the prevalence of foggy or overcast conditions within 50 to 80 miles of the coast frequently rule out the possibility of taking the necessary sights to determine a ship's drift. For these reasons indirect methods were resorted to. Dynamic computations were made and the results compared with temperature and salinity distribution.

The results obtained from this part of the investigation showed that the movements are much more complex and variable than the simple longshore northerly set normally taken for granted. Huge eddies often develop both at the surface and in deeper layers, and counter-currents are not uncommon.

Generally speaking, it can be stated that the surface flow south of Walvis Bay is parallel to the coast in a northerly direction. Farther north the surface waters exhibit an on-shore movement and periodically there is even a complete reversal of flow in lower latitudes. Seasonal patterns could not be clearly defined. Computed currents did not exceed half a knot, but experience has shown that this method produces somewhat low results. Nevertheless, this value agrees closely with the figure of 10–12 miles per day, quoted by the *Africa Pilot*. At 100 metres the movements follow more or less the same pattern as at the surface, apart from in-shore north of *circa* 23° S where the flow appeared to be directed towards the south.

The flow of water at 200 and 400 metres still exhibited a certain degree of variation, but was more clearly defined than in the upper layers. It was predominantly northerly south of latitude 25° S tending to be on-shore close to the coast, while farther to the north the general movement reversed and became southerly, especially in shore. These movements are also implied by the distribution of temperature and salinity, while the existence of a southward flow below the Benguela Current was postulated by Hart and Currie, who believed it to be associated with the process of upwelling. This phenomenon has been encountered elsewhere in regions of upwelling, for example, off the Californian and Peruvian Coasts.

UPWELLING

Upwelling was studied with specific reference to its seasonal variations, the depth affected by it and its fluctuations according to geographical situation.

Seasonal variations in the intensity of upwelling were considerable. With the onset of summer the process rapidly diminished to reach a minimum during autumn or early winter. In fact, the autumn period was marked by an influx of highly saline water into the zone normally marked by cool, upwelled water. As winter progressed the process gained momentum to reach a peak in spring. This latter season was marked by a steep slope of the isohalines and the establishment of a wide band of cool, poorly saline water adjacent to the coast.

The depth affected by upwelling varied considerably according to latitude and season. In the Orange River locality, for instance, water was elevated from depths of 350–400 metres onto the shelf, reducing the salinity of the shelf water to less than 34·7‰. In the Walvis region the depth influenced was about 250 metres and farther north even shallower depths were affected. This also stresses the fact that there are marked variations in upwelling according to geographical situation. The process is intense in the south of the area, a substantial reduction occurring north of the latitude of Walvis Bay.

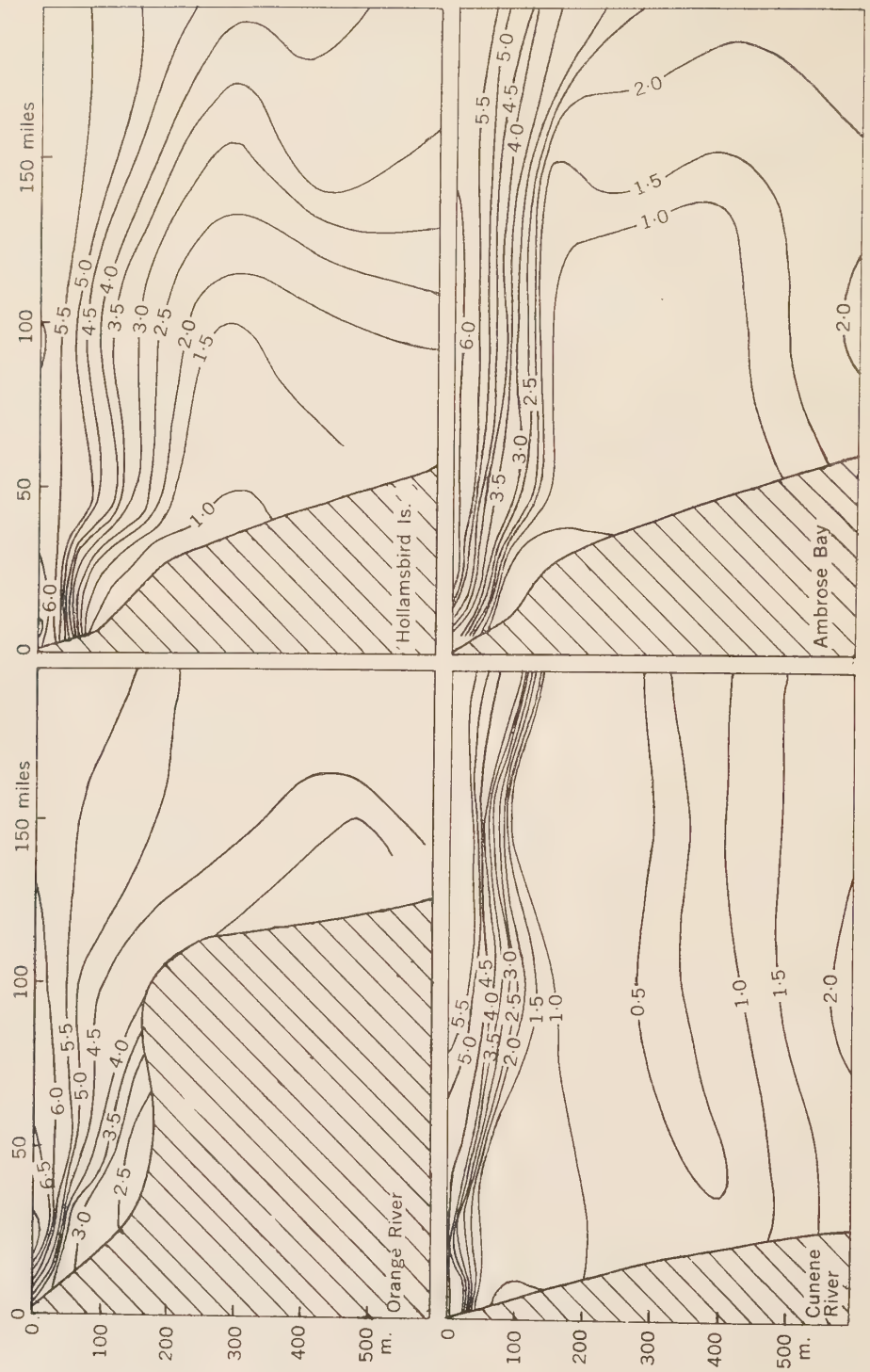

FIG. 4 VERTICAL DISTRIBUTION OF DISSOLVED OXYGEN AT DIFFERENT LOCALITIES DURING OCTOBER 1959.

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CONCLUSIONS

The findings described in the preceding paragraphs are mainly in agreement with what has been reported by other workers in this region.

The investigation conducted by the Division of Sea Fisheries during the years 1959–1961 is without doubt the most extensive and continuous survey ever carried out in this part of the Benguela Current. Much has been learnt about temperature and salinity distribution between the latitudes of 28° S and 17° S and the results will certainly provide a very useful background for further work in more restricted areas. Studies in connection with dissolved oxygen, upwelling and water movements have added to our basic knowledge of the region and will facilitate a future understanding of the productivity of the area.

The findings, coupled with earlier observations made off Walvis Bay by the Marine Research Laboratory, have led to the concept of an oscillation between the cool, poorly saline waters of the south and the warm, more saline waters encountered in the north. A northerly shift of the boundary between these waters would lead to increased productivity and a high spawning intensity of the pilchard, and a southerly shift would have the reverse effect. The extremely poor 1963 season at Walvis Bay, when the average oil yield was not more than ten gallons per ton and when winter-spring spawning was at a low ebb, is a typical example of the influence of this southerly shift of the boundary. Together with planktological and other observations, it offers an interesting field for further study.

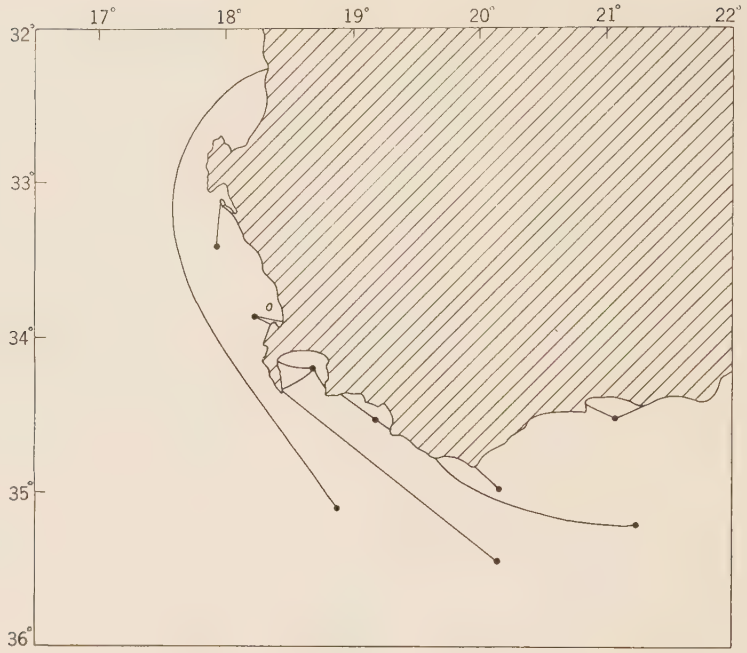

FIG. 5. MOVEMENTS OF DRIFT CARDS, OCTOBER 1964.

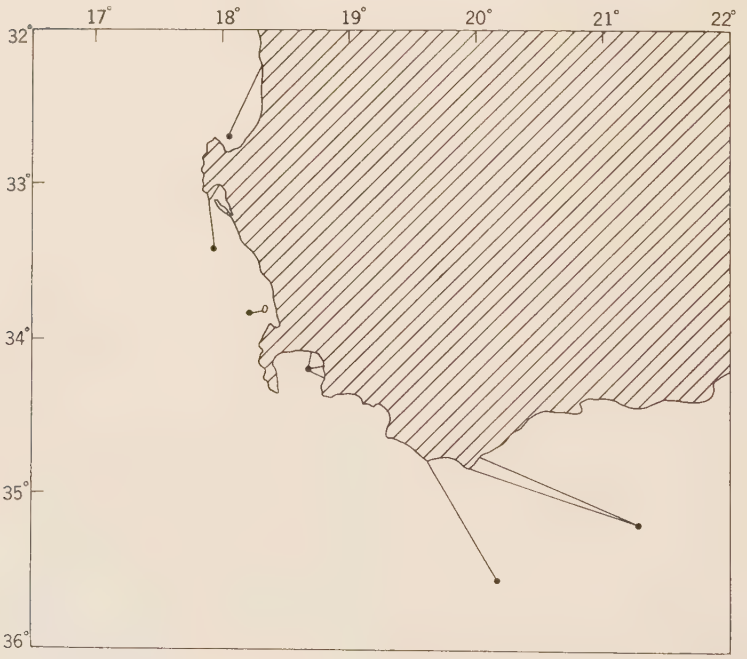

FIG. 6. MOVEMENTS OF DRIFT CARDS, JANUARY 1965.

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CURRENT MEASUREMENTS OFF THE CAPE COAST

C. P. Duncan

In 1963 the Division decided to extend its drift card program to a study of sub-surface and bottom currents. A knowledge of these currents is important because they carry the nutrient salts necessary for the growth of phytoplankton. As they can affect the streaming of trawl nets, the currents should also be understood by trawling skippers. Furthermore, fish tend to line themselves up into a current, and a knowledge of the currents enables the best approach to be made with a trawl. This problem has received much attention in the North Sea, as has the problem of handling gear when the surface currents are different to the subsurface currents. This situation normally arises only when a thermocline acts as a frictionless layer between the two currents.

In October 1964 the Division replaced the plastic-envelope type of drift card with a solid plastic-card which is relatively indestructible. Results to date have been gratifying and current observations from four seasons are discussed here.

Pisa-tube current indicators were specially procured for this investigation, but gave much mechanical trouble. A description of the methods ultimately evolved and a short description of first results are given in the second part of this report. The Woodhead Sea-Bed Drifter was also used. This is a polythene instrument, resembling a red inverted saucer with a long white tail. It bears a number and the inscription:

"Please send details of this number with date and position of recovery to:

THE DIRECTOR OF SEA FISHERIES
BEACH ROAD SEA POINT
CAPE TOWN SOUTH AFRICA."

A short length of copper tube attached to the tail provides just enough weight to sink the instrument gently to the sea-bed where it will be moved by the slightest current. Unfortunately results have been disappointing as 2,100 were released from *Africana II* in July 1965, but only 13 were recovered after two months. This low recovery rate may be due to people keeping the instruments as souvenirs and not sending in the information asked for, or simply disregarding the instructions. An advertising campaign is presently being launched to inform the public about these drifters.

DRIFT CARDS

In October 1964 the Division of Sea Fisheries commenced a new study of the surface currents around the Western Cape. Red plastic cards about $3\frac{1}{2}''$ x $2\frac{1}{2}''$ which floated in water were used, and bore inscriptions in English, Afrikaans, Portuguese and German as follows:

"Please return to:

THE DIRECTOR OF SEA FISHERIES
BEACH ROAD SEA POINT
CAPE TOWN SOUTH AFRICA

with date and position of recovery."

Each card had an identification number. The series discussed here was A1–5,000 and all the cards were dropped between October 1964 and July 1965. The cards were released at certain pre-selected positions. When the finder returns a card to the Division, which he may do "Official Free", its position and date of release and recovery are then known. From this information the direction of the current can be deduced and its minimum speed calculated. Figures 5–8 show the pattern of drift card recoveries for the months of October 1964 and January, April and July 1965 respectively.

In October 1964 (Fig. 5) there was a definite westwards current from 50 miles south of St. Sebastian Bay into False Bay and thence round Cape Point. In False Bay itself and in Walker Bay, the widespread distribution of cards from one point may best be explained by a cyclonic eddy. Such an eddy would result from a westwards flow past these bays. A similar eddy may explain the eastwards flow outside Table Bay.

In January there was a north-westerly set over the Agulhas Bank (see Figure 6). Winds at this time blew from the north-west up to gale force, but according to the currents calculated from the density distribution of the water, the cards show true water movement. An eddy was again apparent in False Bay, and some northerly movement was noticed on the west coast.

Figure 7 shows the pattern followed by drift cards at the height of autumn (April) 1965. A general southerly flow was apparent on the west coast, and even as far as Walker Bay. Over the Agulhas Bank there was an easterly set off-shore. One card which was dropped 50 miles south of St. Sebastian Bay was recovered near Knysna 56 days later. In-shore, between St. Sebastian Bay and Quoin Point there was a strong westerly flow.

In July 1965, the middle of winter, there was a northerly flow towards Cape Agulhas (see Figure 8). There was a westwards flow from Walker Bay

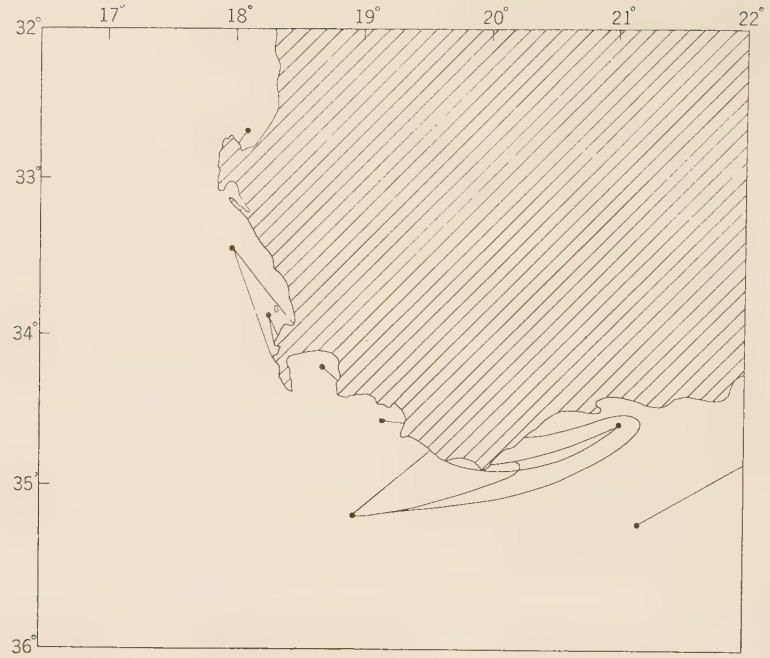

FIG. 7. MOVEMENTS OF DRIFT CARDS, APRIL 1965.

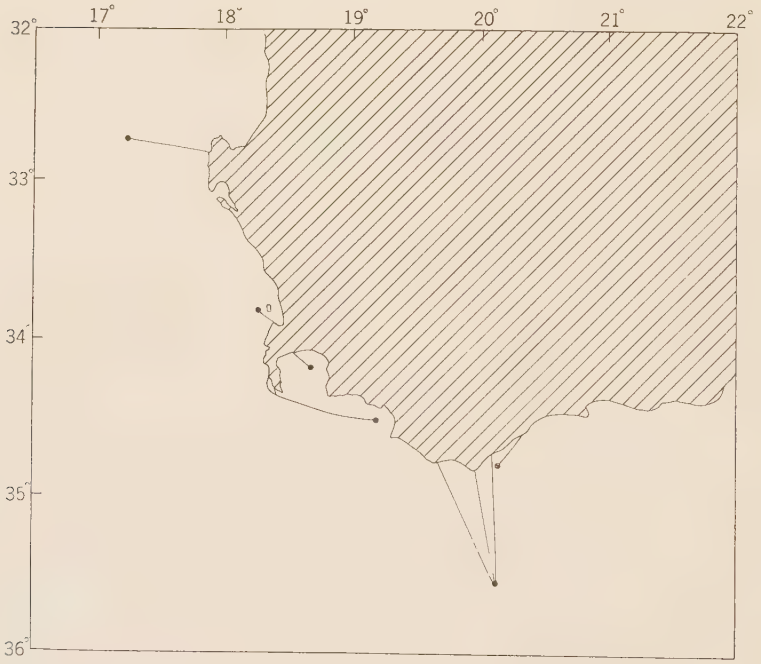

FIG. 8. MOVEMENTS OF DRIFT CARDS, JULY 1965.

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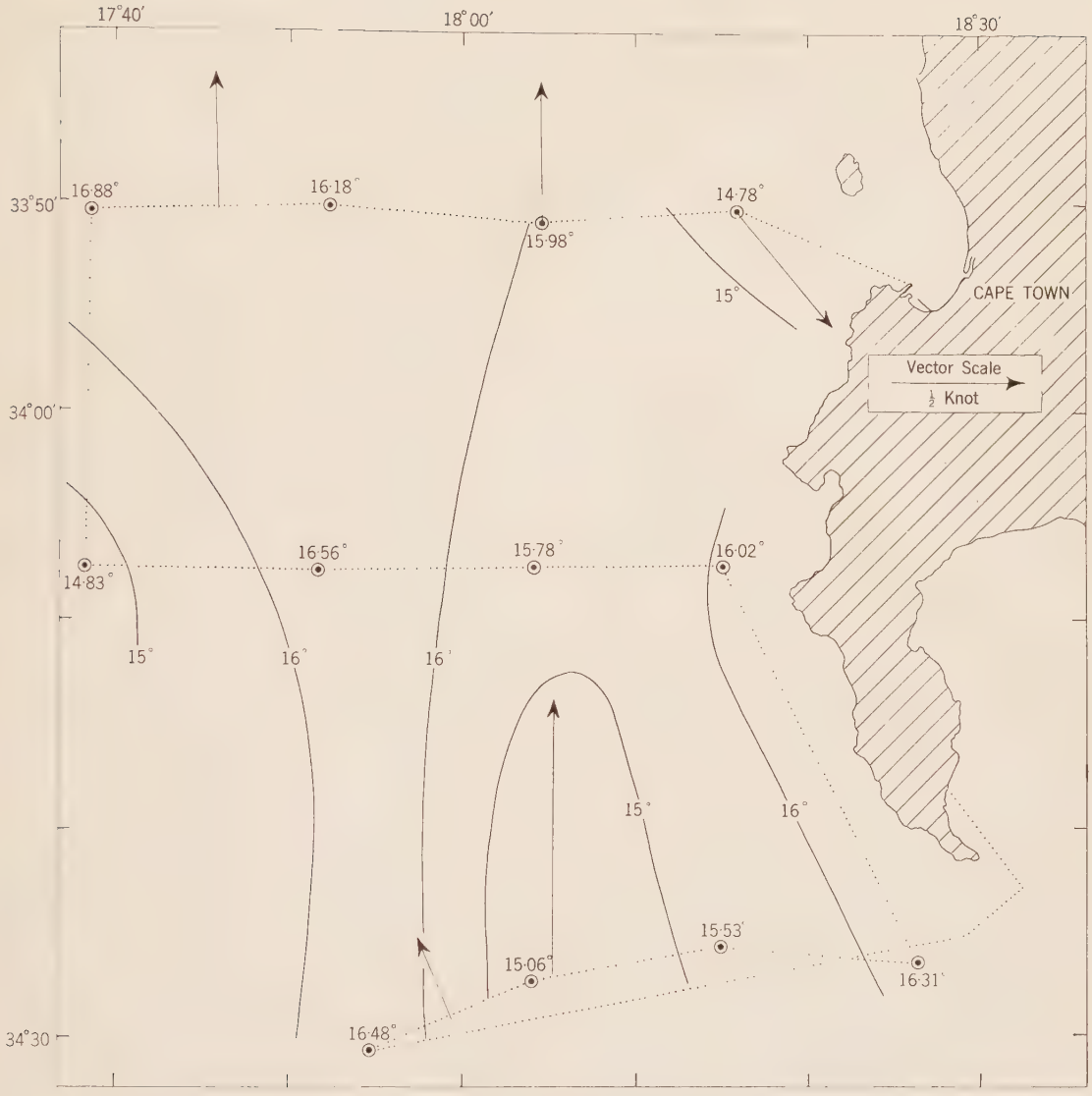

FIG. 9. RESEARCH CRUISE OF R.S. SARDINOPS DURING JULY 1965.

around Cape Point, which is very unusual. In winter the flow is normally from west to east around Cape Point. Conditions on the West Coast were also unusual, the normal southerly flow of winter being absent.

THE PISA-TUBE CURRENT INDICATOR

The R.S. *Sardinops* conducted a survey of currents in the area shown in Figure 9, during 5–8 July 1965 using simple current indicators designed by Dr. Carruthers of the National Institute of Oceanography in England, and calibrated by that institute. During this cruise of *Sardinops* the surface drift was northerly, but the sub-surface currents appeared to be cyclonic eddies.

The current indicators were "Pyrex" bottles containing 4 oz. gelatine topped up with coloured caster oil (Fig. 10). Each was fitted with a magnetized ceramic disc suspended from a fine thread in the gelatine to act as a compass. All fittings were non-magnetic. Each bottle was placed inside a 3′ 6″ buoyant polythene "Pisa-tube" which had two stabilizing vanes. Before use, a bottle was heated in boiling water until the gelatine was liquid and the compass could orientate itself freely.

When required for operation, the Pisa-tube was filled with hot water to delay the setting of the gelatine, and the bottle secured in position in the tube (see Figure 10). The depth of the station was obtained from an echo-sounder and a nylon line (breaking-strain 500 lb.) of the same length was rigged to the tube. An anchor-weight of scrap iron was secured by trawl twine to the end of the line so that if the weight fouled on the bottom the trawl twine would break and the nylon line bearing the equipment could be recovered. The Pisa-tube was attached to the line at the appropriate depth by a stout cord, and above it were tied three small floats. These floats were to ensure that the nylon line was always taut, so that the jerking of the surface buoys did not affect the Pisa-tube. The apparatus was lowered gently into the water, with two large tuna long-line buoys and a pick-up buoy at the surface (see Figure 10). The apparatus was left in the water for one hour so that the gelatine could set. During this time a bathythermograph cast was made and the surface temperature recorded. The equipment was recovered by means of a line hauler.

The slightest current caused the Pisa-tube to lean from the vertical and the gelatine to set at an angle to the side of the bottle. At the same time the setting jelly held the compass so that the direction of the current could be found. The speed of the current was found by comparing the angle at which the gelatine had set with a calibration chart prepared by the National Institute of Oceanography.

Figure 9 shows that there is close coincidence between the surface isotherms and surface flow as shown by the ship's drift. There was an intrusion of cool water 15 miles west of Cape Point and apparent upwelling near Robben Island. Thirty-five miles west of Hout Bay there was a definite cold patch of the same temperature as the upwelled water. A comparison of Figures 9 and 11 shows that the surface currents bear little relation to the subsurface currents, possibly due to the presence of a strong thermocline throughout the area. This frictionless layer can easily separate two currents because it prevents the transmission of turbulent energy which would cause the currents to interact.

The sub-surface currents shown in Figure 11 can best be linked to cyclonic eddies as indicated by the dashed lines. Such eddies by reason of their cyclonic circulation would cause cold water to rise towards the surface and create the effect of upwelling.

These small cyclonic eddies were only discovered because the observations were made in a tight grid with stations only ten miles apart on each line. The effect of a number of such small cyclonic circulations would be the same as that of one very large eddy. Drift card results on the West Coast between Cape Town and Saldanha Bay have shown that such a large-scale effect is always present in summer, and often in winter. There is always a southerly in-shore current in the region, and except occasionally in winter, there is always a northerly current off-shore.

This eddy effect may well be responsible for maintaining large fish and crustacean populations on the West Coast. The larval stage of the rock lobster, for example, is estimated to be about eleven months. In this time, if there were no return currents, the larvae could drift as far away as the coast of Brazil (indeed, a drift bottle released by the South African Division of Sea Fisheries in 1964 was picked up eleven and a half months later at Alagoas in Brazil). Some larvae would undoubtedly perish. But if a large proportion are carried first northwards by the off-shore current and then southwards by the in-shore current, such larvae would spend their larval life circulating to and fro in South African waters. In this way some light can be thrown on the problem of how the rock lobster population manages to restock itself, a matter of some importance when planning closed areas or sanctuaries for the conservation of these resources.

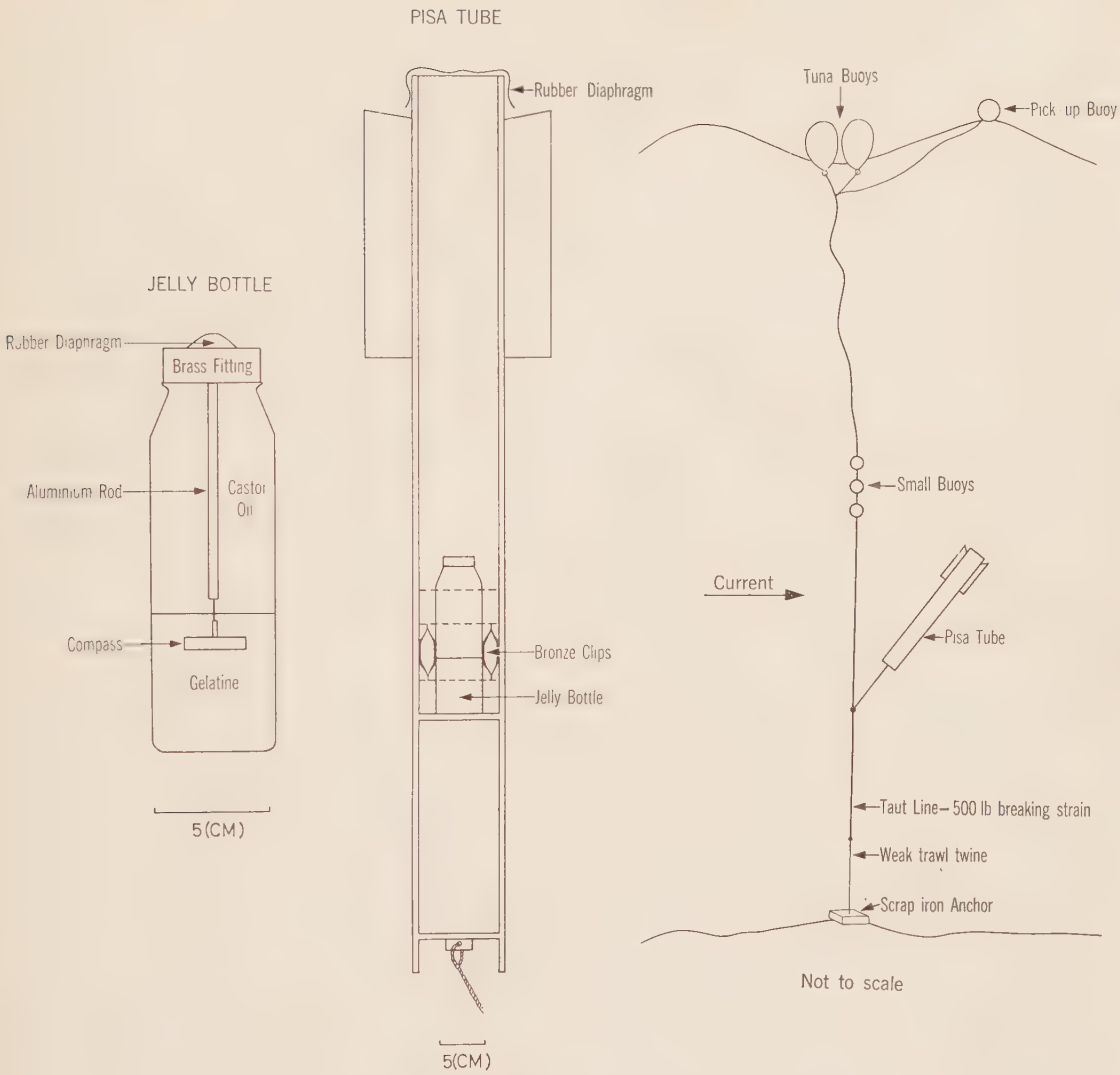

FIG. 10. CONSTRUCTION OF PISA TUBE AND JELLY BOTTLE

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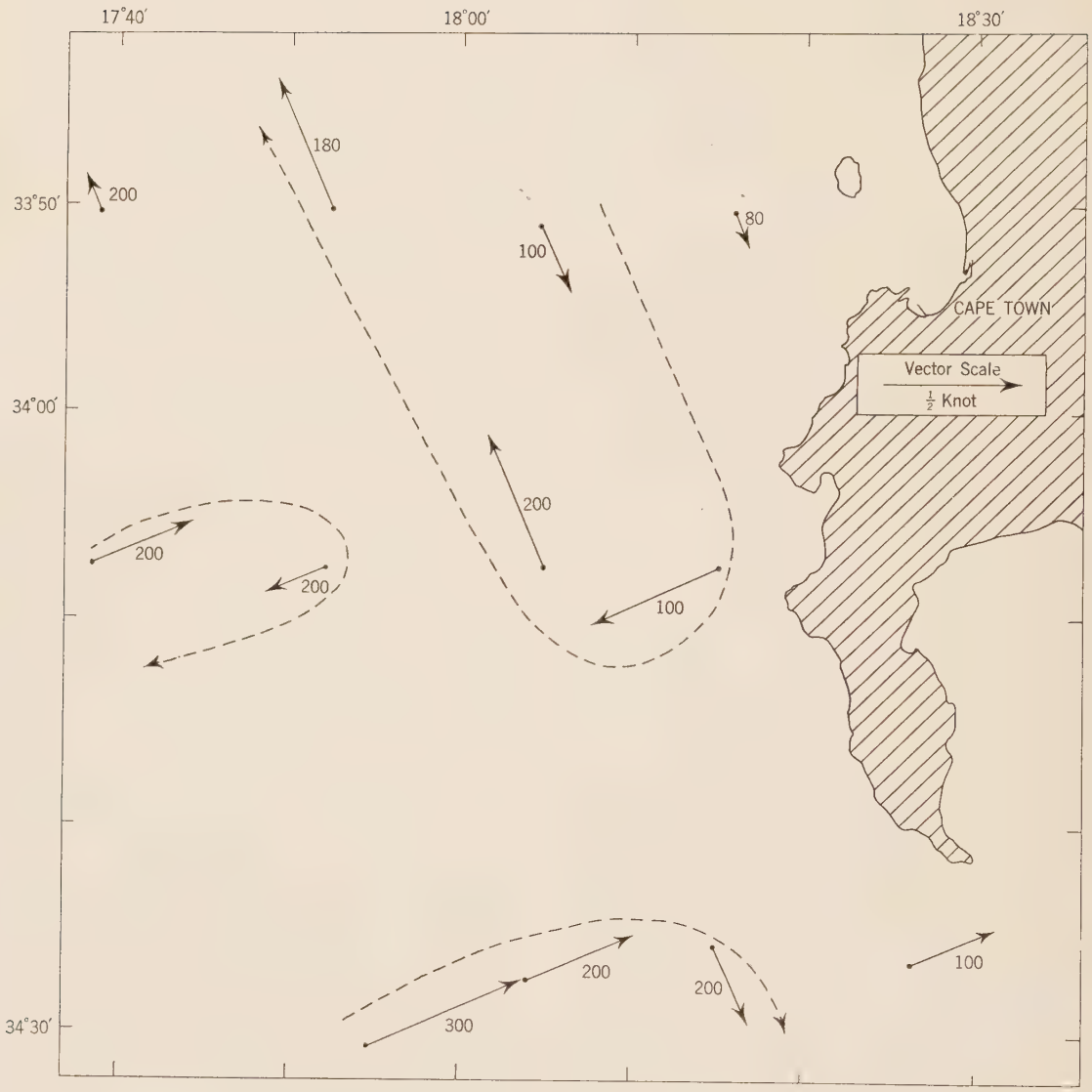

FIG. 11. SUBSURFACE CURRENTS OFF THE CAPE PENINSULA, JULY 1965.

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RADIOACTIVITY IN RELATION TO OCEANOGRAPHY*

L. V. Shannon

During the past decade a great deal of interest has been shown in the natural radioactive environment, but the sea, a mantle covering 71 per cent of the earth's surface to an average depth of 4,000 metres, has been largely neglected. With the advent of nuclear bomb testing in the atmosphere, however, coupled with the problems of radioactive waste disposal, man has found it necessary to investigate the radioactivity of sea water and marine organisms.

The principal types of ionizing radiation from radioactive sources are alpha, beta, gamma and X-rays. Alpha and beta rays are in fact particles, the former being the nuclei or "cores" of helium atoms while the latter are electrons. Gamma and X-rays are forms of electromagnetic radiation, related to light and radio waves, but having much shorter wavelengths.

The alpha-activity of sea water and sea creatures is a field virtually unexplored. This is possibly due to former difficulties associated with experimental techniques. Because alpha-activity accounts for most of the activity in biological materials, the Division of Sea Fisheries is at present engaged on research into the alpha-activity of plankton in conjunction with the Physics Department of the University of Cape Town. The main alpha emitters are members of the three natural radioactive series, the uranium series, the thorium series and the actinium series. Each alpha particle has a specific energy, and by measuring the energy spectrum it is, therefore, possible to identify the nuclide, or nuclides, namely the radioactive source which emitted the alpha particles. Several difficulties, however, have been encountered in the preparation of suitable spectrometric sources, but from the results obtained from total counting, assuming radioactive equilibrium, it appears that various species of plankton concentrate elements such as uranium, radium and polonium by a factor of about a thousand over their concentration in sea water. This implies that in plankton we are dealing with a uranium content of the order of parts per million by weight.

Little work on the alpha-activity of sea water has been published. The concentration of uranium and thorium has, however, been fairly accurately determined by chemical analysis. Uranium is quite evenly distributed with a value of about four micrograms per litre of sea water. This figure may seem very low but it is equivalent to 18 tons of uranium per cubic mile of ocean. Chemical extraction is not at present feasible from a commercial point of view, but adsorption techniques might prove profitable. Pelagic sediments and manganese nodules are rich in ionium, uranium and thorium. By determining the ionium/thorium ratio in sediments the rate of sedimentation may be determined. The chemical procedure is complicated and the results are mainly of interest to the marine geologist.

Often associated with beta emission is the corresponding gamma ray, for example, cesium-137. For this reason gamma and beta emitters are discussed without distinction in this article. The chief natural beta emitters are potassium-40, rhenium-187 and rubidium. Natural potassium contains about 0·01 per cent radioactive potassium-40. The total natural potassium concentration in the sea has been quoted as 0·035 per cent, varying very little with location, and this corresponds to a radioactive potassium content of about 40 micrograms per litre. Many of the beta- and gamma-emitting nuclides present in the sea are cosmic ray produced. Primary cosmic rays strike the earth at the rate of about one per square centimeter per minute at sea-level, while the flux and intensity is variable and highly dependent on geomagnetic latitude. The production rates of the more important cosmic ray produced nuclides are known, these nuclides having been detected in rain, fresh water, sea water and in ocean sediments. Silicon-32 has been detected in ocean sponges by counting its phosphorous-32 daughter (decay product) which in turn decays to sulphur-32.

Perhaps the best known of the cosmic ray produced nuclides is carbon-14. The presence of natural radiocarbon was predicted by Libby* in 1946. Subsequent research by him and his co-workers resulted in the development of the radio-carbon method, which is one of the most powerful tools for dating work in several branches of oceanography. Nuclear bomb testing has resulted in a reported increase of carbon-14 in the atmosphere, and a corresponding increase in surface oceanic water. The radio-carbon tracer method for the measurement of primary production of phytoplankton is well known, although doubts have been expressed as to the interpretation of results.

Two radioactive isotopes of beryllium have been detected in ocean sediments, but little research has

* The South African Shipping News XX (8): 97—99, August 1965.

*LIBBY, W. F. (1946): *Phys. Rev.* 69: 671—672.

been done on their concentration in sea water.

Tritium is produced by cosmic radiation in the atmosphere, its principal source being from the nuclear disintegration of oxygen and nitrogen. Tritium combines readily with hydrogen and oxygen to form HTO, an isotopic relative of water, thus entering the water cycle, and has been detected in Atlantic surface water. Like carbon-14 it has increased notably since the advent of nuclear testing. It has been estimated that hydrogen bombs have produced tritium in amounts comparable with the total natural tritium on the earth.

Numerous radioactive nuclides have been produced by thermo-nuclear bombs or by nuclear reactors, by the fissioning of uranium-235 and plutonium-239. Fortunately most of the fission products have very short half-lives, that is, they are no longer noticeably present after a short time. However, promethium-147, cerium-144, strontium-90, cesium-137 and chlorine-36 have half lives of the order of years (or more). Gamma spectrometric measurements by Soviet scientists of Atlantic Ocean water, indicated that there was a sharp decrease in activity at the depth of the thermocline. Of the short-lived fission fragments zirconium-95 and niobium-95 have been detected in seaweed and sea water. Strontium-90 and cesium-137 have been the subject of a great deal of research, probably due to their biological effects, and relative ease of spectrometric detection. Typical values for strontium-90 range from 0·5 to 3 picocuries per litre, while the values for cesium-137 are slightly higher. (A curie is a unit of radiation representing a disintegration or 'count' rate of $3 \cdot 7 \times 10^{10}$ disintegrations per second, this rate being approximately equivalent to the activity of one gram of pure radium. A picocurie is one million-millionth of a curie). Cesium-137 was detected in the seas off the Cape during 1961, and the results published by Schroeder and Cherry.*

Marine organisms are known for their selective uptake and accumulation of radioactive nuclides. It is not possible here to mention all the radio-nuclides that have been detected in fish and plankton, as different species accumulate different nuclides. While the radio-isotopes of iron, cobalt, manganese and zinc account for most of the artificially produced activity in marine animals, practically none of the above are found in marine algae. Fish and plankton tend to differ in their cobalt-60/iron-55 ratio. The accumulation of beta emitters in certain organs of various sea-creatures can approach the level of 400 milli-microcuries per gram (a milli-microcurie is a thousand picocuries). What the long term effects of such accumulation will be, is uncertain.

The introduction of radioactive materials into the ocean can give oceanographers a valuable instrument for studying the movement of water masses, the rate of vertical and horizontal diffusion, and some of the chemical and biological processes. Much research has been devoted by some nations, the United States of America in particular, to the possibility of introducing large, but controlled, amounts of radioactive matter into the sea in order to trace water movements. Natural tracers too can be used to measure the physical processes in the sea. These tracers include carbon-14, oxygen-18, deuterium and tritium. It would appear that carbon-14 is one of the most useful tracers for geophysical studies, especially when used in conjunction with oxygen-18 data. River run-off and melt-water dilution of the polar oceans cannot be distinguished by salinity data alone. Thus oxygen-18 and deuterium provide the necessary additional parameters, as river run-off in polar regions is greatly depleted of both these nuclides.

The value of tritium measurements as a tool in physical oceanography can be appreciated when it is realised that the ratio of tritium in oceanic rains to the ratio in oceanic surface water is about five to one.

When using isotopic tracers in studying currents we must consider the uptake of the tracers by marine organisms, the migration of the organisms, and their subsequent expulsion of the tracers. It seems, therefore, that the tracer study of water movements is far more complex than it appears at first sight.

Because the level of radioactivity of the sea is much lower than that of the land, it would seem quite feasible to dump radioactive wastes into the sea without any marked increase becoming noticeable. Quantities such as picocuries and parts per million as quoted in this text may sound very small indeed to the average reader. Suppose we were to double or treble the concentration of radioactive materials in the sea. These quantities would still be expressible as picocuries and parts per million. The units are not so important. What is important, however, is the fact that any increase in the amount of activity in the sea may have unexpected effects, unknown as yet, on sea creatures. Nuclear radiation can cause cancer, leukaemia, mutations or even death, if received in sufficiently large doses. Much radioactive waste has, in the past, been deposited in the sea by the nuclear powers. Originally it was

*SCHROEDER, B. W. and R. D. CHERRY (1962): *Nature* 194: 669.

thought quite safe to deposit such material in deep ocean trenches, as the circulation in them was supposed to be very slow, but the results of recent experiments have shown that the turnover of water in these trenches is by no means negligible. The world is on the brink of tremendous development in the peaceful uses of atomic energy, and this is going to pose problems about the disposal of nuclear fuel waste, and other radioactive effluent. Plankton, fish and other marine organisms tend to accumulate certain radio-nuclides; in some cases to an alarming extent. Plankton, forming the first link in the food cycle are especially susceptible. It is felt that a sound background as to the radioactivity of plankton should be established without further delay, in order that any possible increases in the future may be detected.

The Division of Sea Fisheries is now branching out into this field of research, which is fast becoming an important and highly specialised branch of oceanography.

INDIAN OCEAN CRUISES BY AFRICANA II*

M. J. Orren

When it is compared with the Atlantic and Pacific Oceans, the oceanography of the Indian Ocean was until recently comparatively unknown. A few surveys, however, had shown many unusual features including seasonally reversing monsoon currents in the north and the peculiar conditions in the deeper water brought about by lack of mixing with other oceans.

Vast shoals of dead fish and large ocean areas discoloured by plankton blooms had been observed from time to time by mariners in areas generally considered barren.

In 1957, the Scientific Committee for Oceanographic Research (SCOR) of UNESCO proposed an international study of the Indian Ocean, and from this the International Indian Ocean Expedition (IIOE) was born. The success of the International Geophysical Year (IGY) and its established scientific communication channels further stimulated progress in the planning of this expedition.

More than a dozen countries (including the United States, Russia, Japan, the United Kingdom and Portugal) participated and, as part of South Africa's own contribution, S.A.S. *Natal* (South African Navy) and R.S. *Africana II* (Division of Sea Fisheries) completed several cruises between 1961 and 1963 in the area shown in Figure 12 which shows about ten per cent of the surface of the whole Indian Ocean. *Africana II* performed a general deep-ocean survey (see the network of stations in Fig. 12), while *Natal* worked a more detailed survey closer in shore along lines of closely-spaced stations. This report is restricted almost entirely to the findings of the research ship of the Division of Sea Fisheries.

Knowledge of deep-ocean oceanographic conditions in the natural basins surrounding the South African coast plays an essential role in the understanding of coastal oceanography. Coastal waters, in which most of South Africa's fishing efforts are concentrated, are strongly influenced by ocean currents both from the point of view of surface transport of water, and also in the case of upwelling of deep water masses. Tidal currents, weather conditions and the shape of the sea bottom further complicate coastal studies.

Fishery oceanographers are interested in those aspects of oceanography which are linked directly, or potentially, with the presence of exploitable fish stocks, and are thus concerned with areas capable of supporting vast quantities of plankton, on which fish feed. Physical features of importance are (i) current systems and their boundaries, (ii) convergences and divergences, (iii) eddies, and (iv) temperatures.

WATER MOVEMENTS

The Agulhas Current originates in the warm equatorial water carried south by the Mocambique Current and is further strengthened by a stream of warm water flowing round the southern end of Madagascar. Since this warm water sometimes rounds Cape Point and moves some distance up the West Coast, variations in the current strength are important to this coast. Preliminary findings of other workers have shown that the Agulhas Current flows strongest in April and weakest in October.

A further discovery of interest was that comparatively high concentrations of plankton were found on the outer edge of the Agulhas Current 100 miles off Port Elizabeth, where tuna were caught. Counter currents were found on both sides of the Agulhas Current.

Convergence occurs when two water masses tend towards each other and the denser water mass sinks at the boundary or convergence, while the converging water accumulates marine life at the boundary. The Subtropical Convergence, lying about 600 miles south of South Africa, separates cold sub-antarctic water from warmer subtropical water. It was confirmed during the *Africana II* cruises, that the cold water sinks beneath the warm water and moves northwards from the Convergence to form the water mass which later upwells on the West Coast.

Divergence is the converse of convergence; the water masses move away from each other, and deeper water upwells in the area of divergence to replace the departing water. The Benguela Current diverges from the coast and this effect, combined with the action of southerly winds, brings about extensive upwelling along the west coast of South Africa. Upwelling brings nutrient-rich cold deep water to the surface and supports the huge "blooms" of phytoplankton on which pilchard and other pelagic fish depend for food. Zooplank-

*The South African Shipping News XX (1): 87—89, January 1965.

FIG. 12. STATIONS OF THE "AFRICANA II" IN THE SOUTH-WEST INDIAN OCEAN

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ton also feed on the phytoplankton and themselves form food for fish. Variations in upwelling directly cause fluctuations in plankton concentration, and now that the source of this water mass is known, prediction of upwelling becomes more feasible.

The circular motion of eddies causes local convergence or divergence according to the direction of rotation (anti-clockwise or clockwise respectively in the Southern Hemisphere) and, in the Indian Ocean, large oceanic eddies were correlated with significant increases in plankton concentration. Eddies often form over submarine mountains, and the eddy found over the Moçambique Terracè, some 400 miles west of Durban, brought about phytoplankton blooms comparable with those of the West Coast. An accurate knowledge of the position of these mountains and associated eddies could also lead to new areas of potential fishing for such oceanic species as tuna.

TEMPERATURE

Temperature is of great importance in fisheries science, (some fishes can detect as little as 0·03° C change) as it is temperature that influences spawning, growth, migrations and feeding habits. Warm water from the Agulhas Current and cold upwelled water influence the West Coast fishing grounds at various times and affect the commercial fish populations. During the past few years, West Coast temperatures have been steadily increasing, and with the knowledge of the origin of the warm Agulhas water now available it may be possible to discover the causative factors.

When the Agulhas Current—a vast stream 100 miles wide flowing at two to four knots—meets the opposing West Wind Drift south of Cape Agulhas, large irregular eddies form and this area of confused currents is at present under detailed study, since some of the eddies move toward the coast and these patches of water augment local food sources.

The Indian Ocean cruises showed also that the Antarctic Intermediate Water—a deep current originating in the Antarctic and found at about 900 metres depth in the South Atlantic—lay much deeper in the Indian Ocean, and this may well be the reason why the effects of upwelling are less marked along the Indian Ocean shores. Plankton data confirms the conclusion. Where upwelling does occur, for instance off Lourenço Marques and on occasions along the East Coast, large concentrations of plankton are found.

Generally speaking, the volumes of zooplankton found in the Indian Ocean were smaller than those found off the West Coast, with the exception of the upwelling areas and inshore zones. The average winter abundance of phytoplankton in the South West Indian Ocean was much the same as that of the South East Atlantic areas, except that West Coast plankton was very patchy and large blooms alternated with areas of almost no plankton at all, while the Indian Ocean showed a fairly even distribution with the exception of upwelling zones.

Some further findings of interest in the Indian Ocean include the discovery by S.A.S. *Natal* of a shallow patch ("Walters Shoal"), only ten fathoms deep about 450 miles due south of Madagascar, and many previously unknown seamounts.

As a result of these cruises, basic oceanographic data have become available from large areas previously unknown. It is hoped to continue cruises by the *Africana II* on a yearly basis in the South-east Atlantic Ocean to complete the survey of the boundaries of South Africa's fishing areas.

This information can then be combined with findings from the Indian Ocean and from the regular detailed inshore research cruises to help explain the complex interplay of water masses and currents in our main fishing areas, and a refined system of forecasting based on a known set of physical conditions is an ultimate aim.

DEEP-DIVING CRAFT IN MARINE RESEARCH*

A. E. F. Heydorn

INTRODUCTION

The Division of Sea Fisheries has conducted research utilising free diving methods since May 1961, when two members of the research personnel were specially trained at the diving school of the South African Navy in Simonstown. Although diving techniques have proved to be invaluable in the study of shallow water benthic species, these methods become unpractical and dangerous as soon as depths exceed 125 feet. This serious limitation has been keenly felt by undersea researchers throughout the world and has led to the development in several countries, of submersible vehicles capable of carrying scientists to greater depths.

The coasts of South Africa are surrounded by a continental shelf which is proving to be one of the country's greatest assets. Not only does it support substantial fisheries but it is also a source of mineral wealth and possibly even of oil. Unfortunately our knowledge of this shelf is, as yet, very limited and this fact is hampering both the full exploitation and the rational management of these resources. In this regard Professor E. S. W. Simpson, Acting Head of the Oceanography Department, University of Cape Town, very ably described South African marine resources and the urgent need for more advanced research techniques, in an article: "A new world of marine science awaits research", which was published in OPTIMA of June 1964.

ADVANTAGES AND LIMITATIONS OF FREE DIVING

For those not well versed in the techniques and physiology of diving, a very brief description may not be out of place. A diver, usually clad in a special suit to protect him against the cold, is enabled to remain submerged by a supply of breathing air which is delivered at the same pressure as that of the water which surrounds him. If, for example, he works at a depth of 99 feet, the air must be delivered to him at a pressure which is equivalent to the water pressure at 99 feet, that is at four atmospheres. He, therefore, inhales four times the amount of air which he would at the surface. Much of this excess of air dissolves in his body fluids and tissues and unless certain precautions are taken, such as restricting the time he may spend at that depth, or controlling his rate of ascent, he is liable to contract divers' disease (the "bends" or Caisson disease), which can have fatal consequences. This phenomenon limits the depth to which a diver can safely descend and do useful work without special precautions, to approximately 125 feet.

However, the advantages of diving in oceanographical research are considerable. Firstly, direct observation becomes possible, the value of which is indisputable for all disciplines. Secondly, samples, specimens and photographic records can be obtained by direct means and findings are, therefore, no longer subject to more or less blind probings of the seabed. Thirdly, the selectivity which is inherent to most types of collecting of fishing gear, is eliminated. Finally, an assessment of the efficiency of existing collecting and fishing methods and improvement thereof is facilitated by the means of direct observation of operation which diving provides. The application of diving as a research technique can, therefore, lead to immense savings in time and effort required for the collection of data and may also lead to greater accuracy of the findings.

These substantial advantages emphasize the need for improved techniques, which allow man to penetrate greater depths without his being directly exposed to the pressure of the water surrounding him. Even if the physiological problems could be overcome, others would have to be faced, such as the need for more elaborate lighting and collecting equipment at greater depths and the ever-present danger of attacks by sharks in warmer waters.

The answer lies in the provision of a submersible vehicle which can convey scientists in safety to the depths to be explored, in which breathing air is supplied at a pressure of one atmosphere, and which can carry a power supply of sufficient capacity to provide driving power for the vehicle itself, for collecting devices, for cameras and for illumination. Manoeuverability and viewing facilities must be of a high order because prolonged observation of the seabed and its inhabitants is essential. Furthermore, the vehicle must not be too clumsy or heavy as it must be conveyed to research sites by surface vessels of moderate size.

*The South African Shipping News XIX (9): 97—101, September 1964.

THE DIVING SAUCER

Several vehicles which answer to the requirements outlined in the previous paragraph are in existence today, or are still in the process of being developed. One, the diving saucer developed by the research group of Commander J-Y. Cousteau, in France, will be described in detail. Others will be described briefly to give some idea of the diversity in design and of the importance which is being attached to the development of these craft.

Cousteau's diving saucer (fondly named *Denise*) is a lens-shaped craft with a diameter of approximately ten feet and a weight of four tons. It is capable of conveying two people to a depth of 1,000 feet with a maximum submersion time of 24 hours. It is equipped with batteries as a power supply for movement and illumination, a grabbing arm for the collection of specimens and comprehensive photographic equipment. Manoeuverability is unlimited and it has a high safety factor as both ballast and batteries can be dropped in the case of emergency.

This craft would fulfil the needs of marine research in South Africa admirably as it should be low in cost compared to other larger craft (described below), yet be capable of exploring practically the whole of the continental shelf. It has the advantage of being of moderate size and weight so that it can be handled by research vessels already in existence in the Republic. It is also re-assuring that this craft is no longer a prototype as *Denise* has been in use for several years and has proved utterly riable.

OTHER UNDERWATER VEHICLES

Tremendous importance is attached to the development of small, deep-diving submarines for marine research purposes in the United States of America. The development programme for these craft stands under auspices of the U.S. Navy which recently recommended that 333,000,000 dollars be spent on their design and construction. The news magazine, TIME of 5 June 1964 reported on this programme and although the price of these craft is prohibitive, it may be of interest to mention some of them here.

The *Alvin* (named after Oceanographer Allyn Vine), has been built by Litton Industries with Navy funds for the Woods Hole Oceanographic Institute. It is 22 feet long, weighs 13 tons, and has a reasonably conventional submarine shape, but the outside hull serves for streamlining and control only. When *Alvin* submerges, the water enters the thin skin freely. Inside is a seven-foot sphere with walls of high-strength steel 1·33 inches thick to protect the crew from water pressure down to 6,000 feet. Its four viewing ports permit the pilot and observer to see ahead and below, and its three steerable, battery-powered propellers, two of which can swivel to point up or down, give high manoeuverability and a top speed of about 7 m.p.h. Before *Alvin* tries deep and perilous submergence, it will begin practice runs this month in the pleasant shallows near Cape Cod.

The *Deepstar*, similar in appearance to *Alvin*, was built by Westinghouse in collaboration with Jacques-Yves Cousteau, co-developer of the Aqua-Lung. It has a streamlined outside hull containing a thick-walled pressure sphere to protect its crew. Its intended depth limit will be 12,000 feet, and it will have a claw like a giant lobster. Westinghouse intends using *Deepstar* in its own underwater research, besides leasing or selling it to other organizations that feel an urge to explore the ocean bottom. It weighs eight tons and has a crew of three.

The *Aluminaut*, the largest of the research submarines described here, was built for Reynolds Metals Co. by the Electric Boat division of General Dynamics at Groton, Connecticut. It is 50 feet long and made mostly of $6\frac{1}{2}$-in.-thick aluminium, and is capable of cruising comfortably three miles down. It can remain submerged three days with a crew of three.

The *Turtle*, built by Lockheed is lens-shaped to allow it to scoot along the bottom like a flounder. After experiments with a small, self-propelled model, its designer Dr. W. Fiedler decided that the lenticular shape, made of two strong metal saucers joined at their edges, is the best for the moderately deep ocean. It will resist pressure and have more manoeuverability than a sphere. Dr. Fiedler hopes to use it to spy on fish and learn to catch them cheaply. It can repair damaged cables and bury radioactive wastes in the ocean bottom.

In Switzerland, the mesoscaphe, a tourist submarine capable of carrying 40 passengers was developed and built by Auguste Piccard of bathyscaphe fame. A newspaper, *The Cape Argus* of 17 July 1964, reported that this vessel would possibly be brought to South Africa to be used in the search for minerals on the seabed. This appears to be a most unpractical propostion as a vessel of this size is not only unnecessarily expensive but will also be difficult to handle and maintain because of its bulk.

Another interesting report on a submarine research vessel which is being designed for the

fishing industry of the Soviet Union, comes from the British fishing newspaper—*The Fishing News*—and is quoted below:

"New Soviet Bathyscaphe for Sea-bed Discoveries

"The preliminary design of a new bathyscaphe-Sever-II has been submitted for approval to the U.S.S.R. State Committee for the Fish Industry.

"It is intended for studying deep-water plant and animal life, and for observing the work of trawls and other processes of fish catching.

"Engineer Alexander Dmitriev, one of the designers of the bathyscaphe, says the vessel's chief merit is that it will not be tied to the ship.

"Equipped with two engines, it will be able to move about easily in any direction, to lie on the sea bottom, and to pick up objects from the bed. Its design is simple, consisting of a steel hull inside of fibre glass one, and between them are the engines, storage batteries, and ballast tanks that control the vessel's buoyancy.

"The bathyscaphe has mechanical hands controlled by an observer with the aid of an electronic device. The observer also has at hand a cine camera, buttons to switch the searchlights on and off, and a flash bulb for under-water shooting and also a telephone for under-water communication, equipment for recording the noises of sea life and other instruments.

"The vessel is 8·7 metres with a 1·8-metre beam and a depth of three metres. Its range is 80—90 kilometres and it can descend 2,000 metres and remain under water for up to six days."

FINANCIAL IMPLICATIONS

The importance and urgency which is attached to the development of this revolutionary research method has been emphasised in the previous chapter. The applicability of this method to present-day oceanographical research in South Africa, however, makes it necessary to state clearly the financial implications of such an undertaking.

Useful information in this respect was obtained in private communication with Earl E. Hays of the Deep Submergence Research Vehicle Group, of Woods Hole Oceanographic Institution, Massachusetts, U.S.A. He expresses the opinion that a craft built for an operating depth of 1,000 feet (for example, *Denise*), could be large enough to handle a pilot, two observers, have an appreciable equipment capability and be sufficiently manoeuverable. The cost of such a vessel should be between 50 and 150 thousand dollars (R35,000—R105,000), depending on the specific design. The deeper craft (± 6,000 feet operating depth) will cost between R420,000—R700,000, again depending on the specifications.

Assuming that a craft costing about R150,000 would fulfil the immediate needs of marine research in South Africa and could be obtained, it must be realised that this amount would by no means be sufficient for the introduction of this research technique. A diving vehicle is a complicated machine which must be maintained in meticulous order. A workshop (which could be used as storage space) and a maintenance staff of at least two highly trained technicians will be required, as well as a comprehensive range of spares and tools.

Further, operators of the craft (scientific and maintenance) would have to receive intensive training in the country of manufacture.

A research vessel of sufficient size would have to be adapted as mother vessel for the craft by clearing deck space and the fitting of a special hydraulic crane. Equipment for recharging batteries and supplying breathing air would also be required. Ordinary free-diving equipment will be essential for the operation of such a craft.

To summarise, the purely technical requirements besides the craft itself, will entail highly trained maintenance and operating personnel, comprehensive workshop facilities and a specially adapted research vessel.

SCIENTIFIC CONSIDERATIONS

There is an almost unlimited scope for the application of this technique in the field of fisheries research in South Africa. *The prime object of this work would be an accurate assessment of the magnitude of the Republic's various marine fishery resources by direct means.* Thus, a modern survey of the trawling grounds would be of considerable value, particularly as other countries are literally spending millions in the construction of stern trawlers, and travel thousands of miles to fish in South African waters. This method would also be ideal for the study of the depth distribution of various marine organisms. This would be of special value in the case of species of major commercial importance, such as the rock lobster. In this respect there is not only much still to be learnt about the magnitude of the West Coast rock lobster resources, but there are indications that related species may constitute an untapped resource in East Coast waters as well. A craft of this kind would make possible an accurate study of the

behaviour patterns of marine organisms on the seabed during light and dark hours, and their reaction to various kinds of fishing gear. It would also enable scientists to observe pelagic fish, for example, tuna and sharks during long-lining operations, or the shoaling behaviour of pilchards and anchovies.

Use of a diving vehicle, however, would by no means be restricted to fishery science alone. It would be of extreme value to the geologist in his quest for minerals and oil and to the harbour engineer. Here the particular advantage that all *occupants need not necessarily be trained divers* must be mentioned—*the person most qualified in the particular field of study could be taken down for direct observation of his subject.*

A closely co-ordinated research programme which would be of the greatest possible value to the various disciplines concerned, therefore, would have to be devised in the event of the acquisition of an underwater research craft. This would, however, be facilitated to a very large extent by the fact that, wherever the craft may be operating, a continuous photographic record could be made. As this record is made under controlled conditions, results should be far superior to those which can be obtained with cable lowered conventional or television cameras.

A limitation of underwater photography is, of course, that clarity of the water is imperative for worthwhile results. This limitation is felt particularly in the shallow water close to the shore in which the underwater research of the Division of Sea Fisheries is taking place at present. The murkiness of the inshore water is caused by disturbance of the seabed during storms and the effluent of rivers. Experience has shown that the deeper the water, the greater the clarity, even in relatively shallow depths of ten to 100 feet. The effect of this limitation, therefore, should be much reduced in the depths in which an underwater craft would be used.

CONCLUSION

There are substantial advantages when free diving is applied to oceanographical research. These advantages, however, are severely curtailed by the fact that man can only dive to a limited depth when exposed directly to the pressure of the water and also because a diver can only carry a limited amount of equipment. The use of small, deep diving research craft, capable of conveying scientists to greater depths would eliminate these limitations completely. It is the sincere conviction of the writer that no other method could, at this stage, contribute more to the great need for marine research in South Africa.

It has also been pointed out that the scope for such a craft, in the various disciplines of marine research, is almost unlimited. The financial implications are considerable, but it is felt that these could be justified, even for only one field of research—the study of the country's vast but not unlimited fishing resources.

The marine resources are one of South Africa's greatest assets. However, they can only be fully utilized on the basis of sound scientific understanding. The deep diving craft will provide an important means for reaching such understanding.

AN OYSTER SURVEY OFF THE CAPE COAST

A. E. F. Heydorn and G. G. Newman

INTRODUCTION

During the period 9—16 August 1963, the Underwater Research Unit of the Division of Sea Fisheries investigated aspects of the depth distribution and density of oyster populations below the intertidal zone. The investigation was conducted in the area between Knysna and Flesh Bay (See Fig. 13). Five sites were examined along the coastline, namely at Gericke Point, Buffalo Bay, Mossel Bay (two sites) and Flesh Bay. Unfortunately, adverse weather conditions determined to a large extent where diving was to take place, the result being that only in one case did a selected site coincide with a place popular with the commercial gatherers. It will be seen that this does not affect the conclusions which may be drawn from the survey. Due to the preliminary nature and short time allocation of the survey a very simple method of quantitatively estimating the population density was used. This density measurement was taken as the estimate of the number of oysters occurring in a randomly selected square yard of benthic area. Each diver independently estimated the abundance in a few such square yards. These estimates were compared after each dive and conclusions were drawn as to the population density. The variations of population density were such that these animals were either very rare or absent or occurred in such abundance that they completely covered the rocks on which they were found. The fact that the populations usually fell into one of these extreme categories meant that estimation of density was simplified. Records of the depths at which oysters occurred were kept and are all quoted in feet below mean low neap tide level. At all stations a random sample of oysters was collected for classification and estimation of the species' composition.

OBSERVATIONS AT THE DIVING SITES

Gericke Point

Two visits were made to this station. Observations made during the first dive indicated that moderate numbers of oysters (5—8 per square yard) could be observed on the vertical seaward edge of a rocky shelf. This apparently even distribution was found at depths of 6 to 12 feet.

Below 12 feet a sandy bottom was reached. Further search revealed low lying rocks at 20 feet but no oysters were noticed. During the second visit the oyster population on a bottom consisting of large irregular rocks about 30 yards off-shore was observed. Many of the rocks in the area were completely covered by oysters, so much so that counting the number per square yard proved impractical. A conservative estimate of the density per unit area on these particular rocks would be about 50 per square yard. This complete envelopment of rocks by oysters was found within the depth limits 6—20 feet. Below 20 feet sand was again encountered.

Thus many of the rock surfaces examined at this station were completely covered by oysters (commercial collection does not take place at the site). The species composition of a random sample collected in the area was:

Species	Number in Sample	Per cent
Crassostrea margaritacea	62	97
Ostrea atherstonei	1	1·5
Pinctada capensis	1	1·5
TOTAL	64	100

Buffalo Bay

This site was not a typical example of benthic conditions in the area but was investigated as heavy seas prevented diving at any other spot in the area. Diving took place in a large protected gully to depths of ten feet. A thorough search of a large area resulted in the observation of only one specimen of *Crassostrea margaritacea*. Needless to say no commercial exploitation takes place at this site.

Mossel Bay (Yacht Club)

Examination of the sea bed at this site resulted in the discovery of a few dead shells of *Crassostrea margaritacea* and a single, exceptionally large specimen of *Ostrea atherstonei*. As this station is near the harbour area it should be borne in mind that its ecology may not be representative of the area as a whole. No commercial gathering takes place at this site.

Mossel Bay (Die Bakke)

The sea bed at this site is composed of large irregular rocks with the sandy bottom beginning at 12 feet below mean neap low tide level. In the

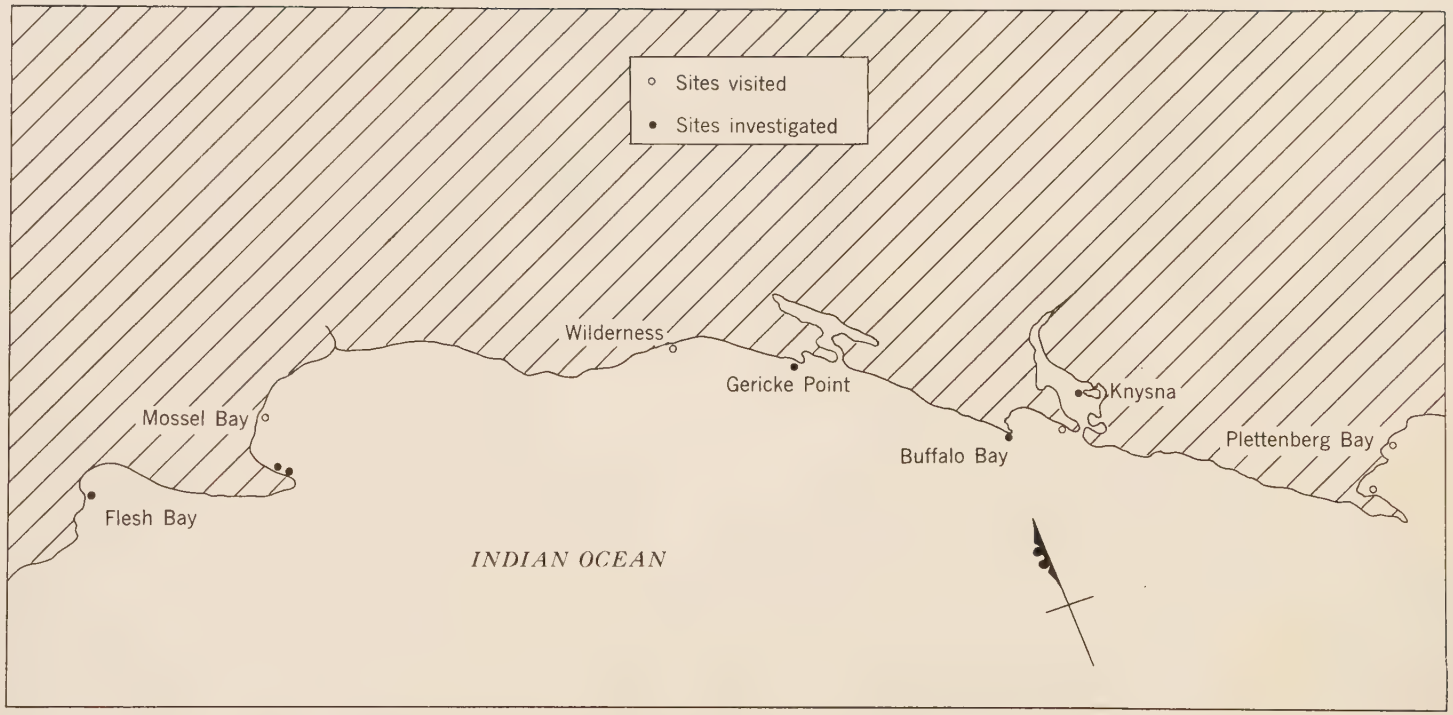

FIG. 13. SITES EXAMINED DURING THE OYSTER SURVEY, AUGUST 1963.

Trigsurvey 1966

region between 0 to 10 feet depth oysters were extremely rare, an estimation of the number per square yard being so small that it could only be roughly guessed and have little significance. In this area red bait (*Pyura stolonifera*) occurred in large numbers. At 15 feet the rocks were partially covered by sand and the density of the oyster population was extremely high, equivalent to that found during the second dive at Gericke Point. Commercial gathering takes place in the vicinity of this station. The species composition of a random sample collected here was:

Species	Number in Sample	Per cent
Crassostrea margaritacea	11	79
Ostrea atherstonei	1	7
Pinctada capensis	2	14
TOTAL	14	100

Flesh Bay

At this site the water was comparatively shallow, with low lying rocks emerging from the sandy bottom at depths of 5 to 10 feet. The oyster population density was similar to that encountered at Gericke Point and "Die Bakke" It is not known whether commercial gathering takes place in this area. The species composition was:

Species	Number in Sample	Per cent
Crassostrea margaritacea	47	100
Ostrea atherstonei	0	0
Pinctada capensis	0	0
TOTAL	47	100

CONCLUSIONS

Conclusions have to be based on observations made at only three diving sites (namely, at Gericke Point, Die Bakke and Flesh Bay) as, firstly, unfavourable weather conditions hampered diving operations to a very large extent and, secondly, two of the five sites visited by the unit were too atypical to provide a valid picture of actual conditions on the sea bed in the area.

From the results of the survey it appears that the population density and depth distribution is very similar at these three sites.

Because of this coincidence of patterns at sites spread along the length of the investigated coastline it is felt that these three isolated observations may be taken as being representative of conditions in the area as a whole.

The population density and depth distribution patterns of *Crassostrea margaritacea* (the commercially exploited species) are such that this species occurs in abundance in the area below the intertidal zone down to a depth of at least 20 feet. This seems to be the case even in areas where commercial gathering does not take place. As this population is not harvested by present-day oyster gathering a large protected breeding population is available to replenish the exploited stock in the intertidal zone. A large supply of spat from the protected breeding population is thus assured. The limiting factor of the effectiveness of intertidal recruitment in heavily exploited areas may be interspecific competition for benthic space. An estimation of the severity of this competition would, therefore, provide a complete answer to the question of whether present-day commercial gathering will ever result in severe reductions in the intertidal population of this species.

ABALONE RESEARCH IN SOUTH AFRICA*

G. G. Newman

In the beginning of 1962 the Division of Sea Fisheries initiated a perlemoen (abalone) research programme. At this time many operators within the industry were complaining that the abundance of abalone was declining and that it was becoming progressively more difficult to make worthwhile catches. A programme was, therefore, designed to cover aspects of the biology of abalone which would provide a guide to the more effective management of available stocks.

THE INDUSTRY

The discovery of large virgin beds of abalone in the early 1950's, combined with a heavy overseas demand for the canned product, initiated a thriving industry in the Republic. For the first few years of the fishery no records of annual catch-sizes are available, but it is known that a peak year occurred in 1954 when the total catch amounted to approximately 1,500,000 individuals. Thereafter the export demand for the product declined, causing a reduction in fishing effort which in turn resulted in lower annual catches. During 1960 the demand increased and two factories operating during this year utilized a total of just over 1,000,000 abalone for canning purposes. Since then the total catch rose steadily to a record production year in 1962 when 1,900,000 animals were collected. During 1963, however, the total annual catch declined slightly to 1,700,000 individuals. This total was maintained during 1964. In 1961 an additional cannery began operations and during 1962 several smaller concerns froze abalone for export in the form of steaks.

Abalone divers operate on a freelance basis, usually owning the equipment they use. Until recently the most popular method of working was from a large dinghy powered by an outboard motor and manned by a diver and two assistants. A portable compressor driven by a petrol motor is kept in the dinghy to supply the diver with air during fishing operations. All equipment, including the dinghy, may be transported overland to suitable launching sites. Favourite fishing spots are often fairly inaccessible and rough, sandy tracks have to be negotiated. For this reason many divers utilize fourwheel-drive vehicles equipped with trailers for carrying both the dinghy and the day's catch.

Abalone are collected on the seabed and placed in net baskets which, when full, are hauled to the surface by crewmen in the dinghy. Working in this manner divers may descend as deep as 60 feet although shallower depths are preferred. Daily catches range from 100—3,000 individual "fish" depending on sea conditions and/or abundance of abalone.

Lately, the popularity of shore-based operations has waned and many divers operate in groups from larger fishing vessels which transport the gear and catch. This system of employing so-called "mother boats" is alleged by some divers to be more efficient and convenient than the land-based method of operation.

The landed catch is either canned or frozen after removal from the shell and cleaning. Canning accounted for 75 per cent of the total annual numerical catch for 1964, the remaining 25 per cent being utilized by freezing concerns. The canned product is exported mainly to the Far East while frozen perlemoen steaks are exported to the United States as well as to the Far East.

At present, conservational legislation affords protection to all abalone below the minimum legal size of $4\frac{1}{2}$ inches. In addition, commercial divers must be in possession of a licence, although the number of licences is not limited. Sportsmen or unlicensed divers may only remove five abalone per day. No other legal restrictions are applied to the fishery.

RESEARCH

The fieldwork associated with the abalone research programme demanded regular underwater observation and collection of individuals for sampling purposes. For this reason a biologist trained as a free diver at the South African Navy Diving School, Simonstown, was made responsible for abalone research.

DISTRIBUTION

The geographical and vertical distribution of *Haliotis midae*, the commercially exploited South African species, was determined by underwater field observations as well as from reports by commercial divers.

This species has been recorded by previous workers along the coastline between Saldanha Bay and East London. Sub-littoral observations by the Division's diving team at Lüderitz (South

*The South African Shipping News XX (5): 93—100, May 1965.

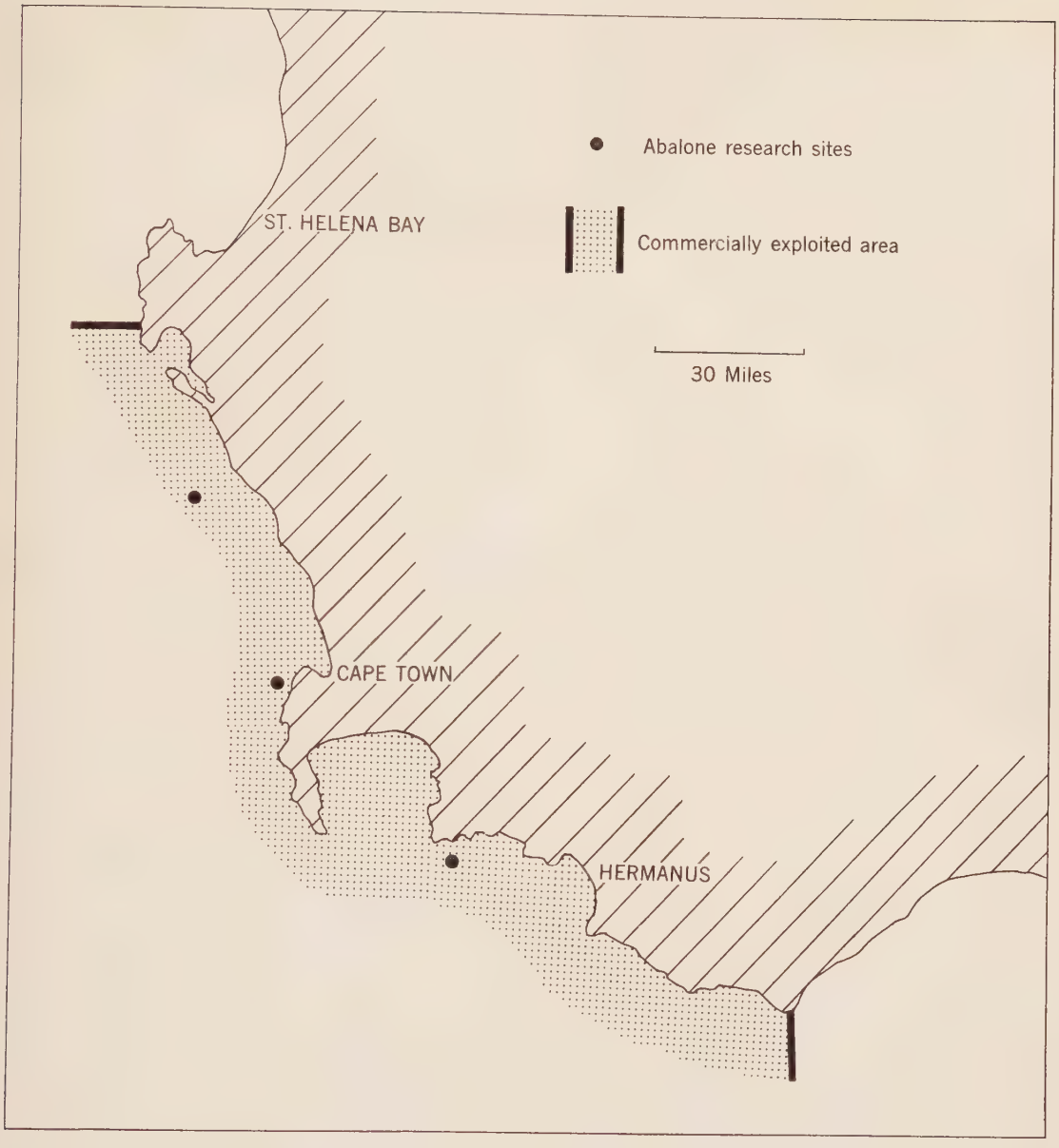

FIG. 14. ABALONE RESEARCH AREA (1962-1964), AND THE ABALONE FISHING GROUNDS.

Trigsurvey 1966.

West Africa), Port Nolloth and Hondeklip Bay failed to reveal the presence of this species north of St. Helena Bay. Although the distribution of the species extends fairly far in an easterly direction, no commercial exploitation takes place beyond Cape Agulhas, presumably due to lack of sufficiently dense populations. A proposed research trip along the South-East and Transkeian coasts should provide an opportunity of comparing the populations within these areas to those of the commercially exploited coastline between Saldanha Bay and Cape Agulhas.

Field observations have shown that the vertical distribution of *Haliotis midae* begins within the littoral zone. The maximum depth at which this species has been recorded by the Division is 75 feet, a depth which agrees fairly well with that reported by commercial divers. Noticeable trends seem to occur in the vertical distribution of abalone of different sizes in the Hermanus area. Juveniles of this species, with shell-breadths below five cm., are found under stones where they are afforded protection from predators. They occur very commonly in shallow protected bays on substrata composed of loose boulders. Larger abalone are not usually found in these areas. Abalone of intermediate sizes, that is 5 cm.—10 cm. shell-breadth, tend to occur more frequently on fairly shallow in-shore reefs, that is 1—6 feet below low water mark, whereas larger abalone are found within a wide range of depths and situations.

Variation in Stock Abundance

The relative abundance of a commercially exploited population at any particular time is reflected by the catch per unit of fishing effort. In the case of the abalone fishery the numerical catch per diver per day is a convenient index which indicates fluctuations of abundance with time. Details relating to each diver's daily catch were obtained from two Hermanus factories for the period January 1960 to December 1964. From these catch figures the mean monthly catch per diver per day has been calculated and plotted for each of the years 1960 to 1963. A decline in availability is indicated by the resultant curve. This may be symptomatic of overfishing of the available population and would thus confirm fears expressed by the industry that abalone stocks are being depleted. Interpretation of the catch for 1964 is complicated by the fact that slight changes in fishing methods occurred during this period. Adjustments have yet to be made to these totals to render them comparable to the rest of the series.

Reproduction

Two aspects of the reproduction of perlemoen are of interest to the fisheries' conservationist. These are the annual breeding cycle and the reproductive potential of the species in relation to its size. Both aspects are receiving attention at the Division of Sea Fisheries.

Spawning of haliotids occurs simply as the release of sperm and eggs into the surrounding water. Fertilization occurs externally in the sea, the egg developing into a free floating larva which, in Japanese and British species, is reported to last from 2 to 11 days. Thereafter, the larva develops a shell and settles on the bottom to form a minute abalone similar in appearance to the adult.

The breeding cycle of the South African abalone has been investigated at three sites along the south-west and south coast of the Republic. Regular monthly samples were collected at Dassen Island, off Sea Point (Cape Town) and at Betties Bay during the period May 1962, through October 1964. The positions of these sites are shown in Figure 14.

The occurrence of spawning may be most conveniently described in terms of changes in the amount of eggs or sperm carried in the gonad, that is as a seasonal loss of gonad material. This is usually expressed as a change in the distribution of gonad weights within comparable samples collected at different times during the year. In abalone, however, separation of gonad material from the rest of the viscera is not practical for bulk sampling. An alternative method of locating the required changes thus had to be used.

This latter method depends on the fact that in the region of the shell-apex the visceral mass consists of gonad and digestive gland only, the former completely encompassing the latter in the case of a well-developed ovary. By sectioning the visceral mass in this region (the position and appearance of the section is shown in Figure 15), an index reflecting the gonad bulk of a particular specimen could be obtained. This so-called "gonad bulk index" was calculated in the following way. The appearance of each section was recorded photographically. From projected photographic records the area of the whole section as well as that occupied by the gonad only, was measured planimetrically. A gonad bulk index was then calculated from the formula $G.B.I. = \frac{\text{gonad area}}{\text{total area}} \times 100$. Large changes in gonad size would obviously be reflected by changes in this index.

Spawning activity was thus assumed to have taken place when statistically significant changes occurred in the distribution of gonad bulk indexes within comparable samples collected at monthly intervals. The months between which such differences could be shown are listed in Table I.

TABLE I: ABALONE SPAWNING PERIODS

Research Site	Period in which spawning took place
House Bay, Dassen Island ..	September—October 1962 June—October 1963 February—March 1964
Sea Point, Cape Town ..	September—November 1962 July—November 1963
Stony Point, Betties Bay ..	October—December 1963 March—April 1964

From Table I it is apparent that at some sites, namely, Stony Point and House Bay, evidence indicates that abalone may spawn twice during a twelve-month period. In addition the release of reproductive material at the different research sites seems to take place at more or less the same time, that is, during Spring and early Autumn.

Investigation of the fecundity or reproductive potential of female abalone of different sizes has just commenced at the Division of Sea Fisheries. Ideally this relationship can be illustrated by the form of a mathematical curve relating the number of eggs carried to the size of the animal expressed in terms of body weight and/or shell-breadth. A few preliminary experiments have been done to establish the feasibility of doing egg counts for the species. The estimates of the number of eggs carried by individual abalone were made by carefully dissecting and weighing all ovarian material. Small pieces were then removed from various regions of the dissected ovary and accurately weighed. All eggs within these subsamples were then counted and the number of eggs per unit weight was thus obtained. From this value and the total ovary weight the number of eggs carried by the whole ovary was easily calculated. To ensure that the ovaries used for these experiments had relatively well-developed eggs, none of which were lost due to spawning, the experimental animals were collected when their gonad bulk index had reached maximum level.

In spite of these safeguards, the estimation of the total number of eggs was complicated by the fact that at least two different size-categories of eggs have been found within the gonads. These categories included eggs with diameters of 0·15 to 0·08 mm. and $< 0·05$ mm. respectively. If it is assumed that only those eggs in the large size-category are released at the next spawning, then the number of eggs available from one experimental animal amounted to approximately 12,500,000. This particular specimen had a shell breadth of 12·75 cm. and weighed 450 gm. The gonad weight amounted to 53·1 gm. The abalone fecundity estimates at the Division are virtually in their infancy and as such the above-quoted figure must be regarded only as a tentative estimate of the number of eggs carried by a medium-size abalone. Many more egg counts remain to be done before the proposed curve relating fecundity to size becomes available.

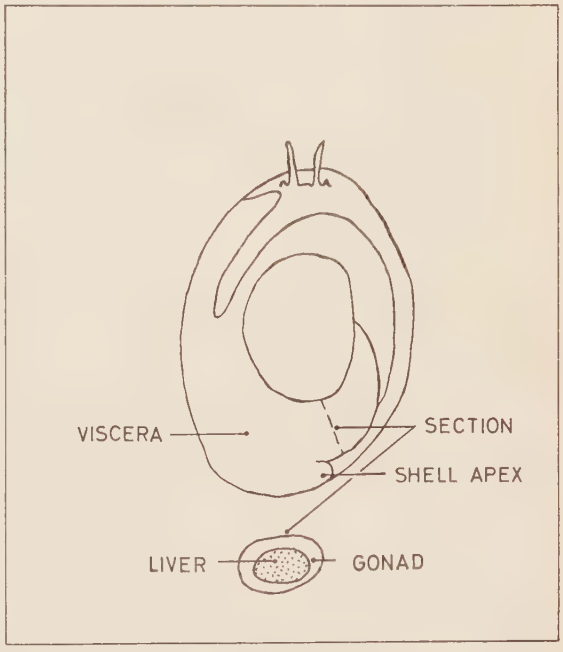

FIG. 15. POSITION AND APPEARANCE OF GONAD BULK INDEX

Growth

A determination of the growth rate of abalone is of the utmost importance for the regulation of the fishery. Much research effort, therefore, has been expended by the Division in an attempt to establish this. Two methods have been utilized to describe growth in terms of increases in shell length and breadth with time.

The method of determining the growth rate of smaller individuals, that is, those below 5 cm. shell length, is basically dependent on the fact that

Fig. 16 A tagged Abalone, *Haliotis midae*

after each spawning a large and well-defined group of small abalone enter the population. If growth is fairly uniform this group will, in time, maintain its identity although the size of the individuals will increase at a rate dependent on the growth rate. Eventually, as individuals within groups become larger, their growth rate declines and becomes more variable. Previously recognizable groups of individuals begin to merge until it is no longer possible to distinguish them. This method of growth determination is thus only suitable for smaller-sized abalone. Groups within a large collection of small abalone can be aged if the annual spawning cycle is known and, by calculating the mean value of each of these groups, a relationship between age and size can be obtained. Many small abalone were collected by divers of the Division in the vicinity of Betties Bay. These collections were analysed and indicated that a shell length of 5 cm. is attained after at least two years.

The growth rate of medium-sized abalone, namely those within the size range 5—12 cm. shell-breadth, was investigated by means of tagging. During the period January 1962 to June 1963, a total of 2,645 *Haliotis midae* were tagged by the Division's diving team at Betties Bay. The abalone were marked by plastic discs attached to the shell by means of non-corrosive nickel pins. A tagged shell is illustrated in Figure 16. Each tag bore a number which was noted together with details of the shell length and breadth measured by means of vernier calipers. At regular intervals divers from the Division conducted systematic searches to recover previously tagged abalone for remeasurement. A total of 146 animals were recovered and found to be suitable for growth determinations. Final analysis of these data to calculate seasonal fluctuations of growth rate (if any), as well as to build up a composite growth curve remains to be done. There are indications, however, that the growth rate of this species is slow. Animals with a shell-breadth within the size range 6—7 cm. can be expected to increase their shell-breadth by only 0·8 cm. during a one year period. This mean annual growth rate decreases in larger animals, being only 0·5 cm. in the case of abalone of 9—10 cm. shell-breadth.

The growth rate has been expressed in terms of increases in shell dimensions because these are most convenient to record. It is, however, important to relate these changes to increases in abalone flesh weight, as well as to changes in other shell dimensions. These relationships are being studied throughout the size range of the species. In addition, abalone from different areas are being compared to note differences in shell shape and animal weight due to different environmental conditions.

Movement

Noticeable variations in the vertical distribution of different sized individuals suggest that the South African abalone must be capable of some movement. Such movements exhibited by our own species would not be unexpected as other investigators have reported that related abalone are fairly active. It was accordingly decided to investigate the movement of *Haliotis midae*. This could most conveniently be done by means of the tagging experiment described above. During this experiment divers collected abalone and returned them after tagging to well-defined areas along the coastline. The site of release after tagging was thus known for all tagged specimens. Abalone were then recovered in the course of systematic searches conducted at suitable times after tagging. During these searches a modified grid system was utilized to locate the position of recovery and, since the position of tagging had been recorded, it was possible to calculate the minimum movement within a known time period. A total of 232 such records were found to be suitable for the study of movements. Movements of over 300 yards were recorded for periods ranging from 104—558 days. Within just over a month one, three and four individuals covered distances of approximately 132, 176 and 220 yards respectively. The minimum incidence of movement of the tagged population was also studied by estimating the percentage of recoveries which moved beyond the boundaries of the areas to which they were returned after tagging. These estimates showed a fairly high incidence of movement. Within periods of 27—112 days 64 per cent of all tagged abalone moved beyond the areas in which they were replaced. After longer tag-return periods, such as 160—180 days, a higher incidence of movement was indicated, namely 78 per cent.

The general picture of movement which emerges from this study, is that *Haliotis midae* within the medium-size ranges, namely 5—12 cm. shell-breadth, are by no means stationary animals. Movement is common and relatively large distances are covered. These movement characteristics explain the trends in the vertical distribution of different-sized abalone at the research site, and imply that at least juvenile and intermediate-sized abalone must indeed move to change their depth or situation.

CONCLUSION

In spite of the implementation of a minimum-size limit as well as a divers' licensing system, there are indications that the abalone populations along the Republic's coastline are being overexploited. The findings of the abalone programme in this respect confirm complaints by the industry that stocks are being depleted. To counteract this state of affairs the Division is contemplating the introduction of additional measures to regulate the fishery. The establishment of sanctuaries, an annual catch quota and revision of the minimum size limit are all being considered.

The decision to implement the above legislation should ideally be based on a scientific assessment of the state of the exploited population as well as an evaluation of the effectiveness of the contemplated measures. The abalone research programme has been designed to provide the facts for such assessment and evaluation. On its completion, therefore, the Division should be in a favourable position to rationally manage this marine resource.

TRENDS IN THE PILCHARD FISHERY, 1950—1965*

G. H. Stander

Contrary to what was formerly believed, it is today generally appreciated that commercial exploitation does not reduce the strength of a fish population provided it is exercised at or below a safe level, called the "maximum sustainable yield". A population subjected to fishing operations compensates for this loss of numbers in a variety of ways, for example, by more rapid growth and earlier maturity. Overfishing, on the other hand, forces the exploited population to adapt itself at a lower level of numerical strength and can cause permanent damage to fish stocks. It will, therefore, be obvious that one of the primary objects of the study of population dynamics is to establish the maximum sustainable yield.

A variety of protective measures are applied in fisheries management. These include *inter alia* minimum mesh-sizes for fishing nets, catch quotas, closed seasons, boat limitation (numbers and/or tonnage), limits imposed on reduction plant capacities and various combinations of these measures. In the Republic conservation measures currently provide for a closed season, boat and reduction plant capacity limitation and regulations pertaining to mesh-size of nets. The effectiveness of the various measures will be dealt with in some detail at a later stage.

The commercial catch of pilchards has exhibited striking fluctuations during the past fifteen years. It dropped below 100,000 short tons in 1956 and subsequently soared to reach a record figure of over 450,000 tons in 1962. During this period the fishing effort also underwent a certain degree of change. The purpose of this report is to relate the variations of the commercial catch to internal and external factors and to see what can be gleaned from the available information.

The South African pilchard (*Sardinops ocellata*) is a member of the Clupeoid family and is closely related among others to the Californian sardine *Sardinops caerulea*, and the Australian sardine *Sardinops neopilchardus*. It is known to occur from north of Walvis Bay on the South West African coast to the north coast of Natal. One of its chief competitors for food is the anchovy *Engraulis japonicus*. A cursory glance at Table II will show the close inter-relationship between the two species.

TABLE II

Pilchard	Anchovy
Occurrence: Highest concentrations in area between Stompneus Bay and Cape Agulhas and the area between Lüderitz and Cape Cross.	Highest known concentrations in area between Stompneus Bay and Cape Infanta. Big shoals also known to be off Walvis Bay and Lüderitz.
Feeding: Mixed diet consisting mainly of phytoplankton (mainly *Nitzschia*, *Thalassiosira*, *Skeletonema*, *Chaetoceros*, *Thalassionema*, *Coscinodiscus*) and zooplankton (mainly *Centropages brachiatus*, *Calanoides carinatus*, *Calanus* spp. and *Euchirella* spp.).	Mixed diet consisting of phytoplankton (mainly *Thalassionema*, *Nitzschia*, *Thalassiosira*, *Skeletonema*, *Chaetoceros*) and zooplankton (mainly *Centropages brachiatus*, *Oithona* spp. and *Calanoides carinatus*).
Spawning: July to February with spawning peaks normally in September—October and January—February.	October to February with major spawning peak in November to December.
Oil Content: At a maximum during May to July.	Considered to coincide with peak season of pilchards, on a basis of seasonal occurrence of juveniles, i.e. spawning cycle.

CATCH FLUCTUATIONS

As mentioned earlier, the commercial catch of pilchards fluctuated to a marked degree during the past 15 years. From a very modest 95,093 short tons in 1950 it steadily rose to reach a figure of 187,424 tons in 1952, falling to 150,987 tons in 1953. During the years 1954 to 1957 catches were low, a total of only 84,156 tons being landed in 1956. The years 1957—1963 saw the commercial catch of pilchards soaring to unprecedented levels, an all-time record catch of 452,735 tons being landed in 1962. The catch for 1964 was 282,301 tons and at the time of writing (early June) the landings for the current fishing season have attained approximately 216,457 tons. It is difficult to foresee what figure will be realised in 1965, but it is rather doubtful whether it will be appreciably above 300,000 tons.

The general trend as far as the landings for the period under review are concerned, can, therefore,

*The South African Shipping News XX (7): 70—75, July 1965.

conveniently be summarised as a period of fluctuating catches (1950—1957), followed by a period of rapidly soaring landings (1958—1963) and finally a period of apparently declining catches (from 1964 onwards).

Due to a reduction in the average size of the fish landed, there has been a corresponding increase in the number of individuals caught per unit weight. In the early nineteen fifties, for example, a weight of 100,000 tons was roughly equivalent to 600 million individuals; in more recent years the ratio has at times increased to over 1,000 million fish per 100,000 tons of landed weight of pilchards. Briefly it can be stated that 574 million individuals were caught in 1950. This figure increased to 1,245 million in 1952 and varied between 493 million and 899 million during the period of fluctuating catches referred to in a previous paragraph. In more recent times it has soared to attain a record figure of 4,585 million individuals in 1963. *It is, therefore, clear that increased landings coupled with a sharp decline in average size of the pilchard led to grossly increased numbers of fish being caught.*

FISHING EFFORT

Prior to 1950 unrestricted fishing for pilchards was permitted. Nevertheless, the catches during this period were low, due among others to the limited hold capacity of the fishing fleet, relative inexperience of the fishermen and the absence of modern fishing aids.

Subsequently, a variety of restrictive measures was introduced as follows—

(i) the provision of a minimum mesh-size for pilchard fishing nets in 1950,

(ii) the limitation of the number and reduction capacity of fish meal plants, in the same year,

(iii) the imposition of a closed season in 1951,

(iv) the limitation of boats employed for pilchard fishing in 1953,

(v) the limitation of pilchard canneries, also in 1953 and finally,

(vi) the imposition of a catch quota of 250,000 short tons of pilchards and maasbankers in 1953.

At this stage it may be advisable to consider briefly the impact of the various conservational measures on the pilchard population. Measures pertaining to mesh-size are aimed at preventing the catch of undersized, sexually immature fish; the object is to ensure that each fish is afforded at least one opportunity of spawning. The effect of the closed season, which was selected to coincide with the major spawning season of pilchards may be disregarded for practical purposes as it covered a period which had in previous years been noted for rather poor catches. Likewise the limitation of reduction capacity is of little practical significance as it has never really been a limiting factor. In fact, the annual landings comprise a small percentage of the fish that can theoretically be handled by the reduction plants.

The most effective conservation measure being applied currently (the catch quota has been abolished) is the limitation on the hold-capacity of fishing vessels. Apart from the availability of fish the potential fishing effort gauged in terms of hold-capacity constitutes the only limiting factor on the size of the commercial catch.

The total hold-capacity permitted increased from 4,850 short tons in 1950 to 8,320 tons in 1953. Up to 1960 this figure showed only minor fluctuations, but subsequently there has been an increase to 9,840 tons in 1962 and currently the aggregate tonnage is 11,902 tons. During this period the fishing fleet underwent a metamorphosis in terms of the size of boats employed. While smaller boats were used there was initially an increase in the number of vessels in operation from 150 in 1950 to 229 in 1953. With the advent of larger vessels the total number has decreased considerably and in spite of the increased hold-tonnage there are currently only 125 boats in operation supplying factories with an aggregate reduction capacity of 254 tons per hour. New concessions are currently being granted and an increase of 20 per cent in boat hold-capacity is anticipated.

To assess the effect of these developments on the fishing effort quantitatively, is beyond the scope of the present report. A few remarks, however, should suffice. In spite of the fact that there has not been a drastic increase in hold-capacity in recent years, it should be remembered that the modern pilchard boat is a much more efficient unit than its predecessor of a decade ago. The present-day boat is a large vessel capable of practically all-weather operations and equipped with the most modern available fish finding devices and large nets. Notwithstanding the fact that the number of boats has decreased, it does not follow that the fishing effort has diminished; on the contrary, the decrease in numbers has been made good by increased efficiency and hence it is probably wise to regard the effort as having remained constant or increased somewhat.

POPULATION SIZE

Population estimates derived from tag returns to date have proved to be unreliable. In the absence of other information the relative spawning intensity will therefore be regarded as indicative of adult population size. This seems feasible in view of the fact that the annual catch of pilchards has shown moderately good correlation with spawning intensity expressed in terms of ova per haul and based on data collected in the routine research area of the Division of Sea Fisheries.

These results indicate a low adult stock level during the years 1955 to 1958, increasing to reach a broad peak over the period 1960 to 1963. Referring to the section dealing with fluctuations in the commercial catch, it will be seen that these two parameters exhibit similar trends.

If the downward tendency (in spite of increased effort) experienced in 1964 is assumed to be indicative of a decrease in stock (due to depletion by fishing), the prospect of anything but a relatively modest catch in 1965 is rather remote.

RECRUITMENT

Recruitment will in the first instance, be briefly considered in the light of results obtained from young fish surveys employing the blanket net method of fishing. It is fortunately possible to consider both juvenile pilchards and anchovies in this context.

It is not surprising, in the light of the comparison drawn between these two species in one of the introductory paragraphs, that the tendencies exhibited in terms of blanket net catches are identical. Recruitment of young fish was rather low for both species during 1958 to 1960; from 1961 to 1962 there was, however, a dramatic increase. The year 1963 was occasioned by a sharp drop and 1964 saw no improvement in the situation.

Even more revealing is the ratio of anchovies to pilchards in the experimental catches. While the two species were represented equally in 1958, anchovies outnumbered pilchards by up to 4 : 1 in the following three years. The balance was temporarily restored in 1962 when the ratio was 1·4 : 1 in favour of anchovies. During the past two years, however, juvenile anchovies have exceeded pilchards by between 12 and 16 : 1 in the blanket net catches. *The possibility is not excluded that, as in the case of California, the pilchard is rapidly losing ground to a competitor, the anchovy.*

The combined pilchard tagging experiment conducted by the S.W.A. Administration and this Division has proved beyond doubt that there is a definite relation between pilchards in the Republic and South West African waters. The recruitment of fish from South West African waters obviously plays an important part in maintaining the Cape stock at a commercial level. Nevertheless, it should be borne in mind that the quota in South West Africa has risen sharply to reach a figure of 720,000 tons per annum. Whether the resources will be able to stand this additional drain and to what extent it will affect stocks in our waters (that is, replenishment due to a southerly migration) is an open question. However, it does give cause for concern and creates a degree of uncertainty. But when drawing such conclusions the possibility that the observed trends are due to natural fluctuations within the population must not be excluded. Under the circumstances caution and a conservative approach are indicated.

SIZE COMPOSITION OF THE COMMERCIAL CATCH

An examination of the size composition of the commercial catch clearly shows that the years between 1950 and 1964 can be divided into two periods, namely a period prior to 1958 when the catch consisted mainly of fish of standard length above 21 cm. and a subsequent period of fish below 21 cm. in length. The sudden change in size composition occurred in 1958 and since that year vast quantities of juvenile pilchards have been caught annually. Thus, for instance, in the pre-1958 period the mean length and weight of the landed fish were 22—23 cm. and 136—155 gm respectively; since 1958 it has changed dramatically to 17—21cm. and 71—138 gm. One major impact of this phenomenon on the fishery is the fact that, as pointed out earlier, the number of individuals per unit of landed weight has increased out of proportion to the increased landings. The predominant appearance of smaller fish classes in the catches coincided with the period of intensive spawning recorded during the years 1959—1963.

The absence of small fish from the catches prior to 1957, and in particular during 1954 and 1955, should probably be interpreted as a lack of recruitment resulting in low catches over these earlier years. In 1957 a new year class appeared in the 16 cm. size range, but the bulk of the rather poor catches was composed of the already depleted older year classes.

As a result of this severe depletion of the older year classes a single year class in the 18—19 cm. size range had to bear the brunt of fishing in 1958.

It was nevertheless so strong that it permitted a record catch of over 200,000 tons of pilchards. Recruitment in the years that followed was, judging by size composition, very satisfactory and accounted for unusually high landings in 1959 to 1963/64. From 1961 onwards there was once again a slight increase in the bigger year classes. The record catches of 1961 and 1962 were mainly attributable to a strong group of fish in the size range 19·5—22 cm. The success of the 1963 catch was due to two year classes, namely, a new year class appearing in the 15—17 cm. size range and an older year class (survivors from the previous year) in the 20—22 cm. range. The former year class was probably also responsible for the moderate success of the 1964 season. Fishing during the current season has been mainly on the 18—21 cm. size group.

THE INFLUENCE OF ENVIRONMENTAL FACTORS

Very satisfactory agreement has been found between the mean temperature of the 0—50 metres layer of a certain off-shore area of the sea in one year, and the commercial catch of pilchards in the following year. With the aid of this correlation the Division has been able to forecast the landings of pilchards with a significant degree of accuracy. It has not been possible to date to find an explanation for this relation between the two variables.

Temperatures during 1964 were rather high in the area studied, being up to 2° C above the 15-year average in certain seasons. This phenomenon would normally be interpreted as a good omen for the future, but as the high temperatures appear to be at least partly due to the penetration of warm Agulhas water into the area off the Cape West Coast, it is doubtful whether it should be regarded as indicative of possible good catches. Compared with the rich Benguela waters the Agulhas Current is comparatively poor in nutrients and this influx of warm water can rather be expected to have an adverse effect.

FUTURE PROSPECTS

It is rather hazardous, on the grounds of the limited amount of information available, to speculate too freely about the future prospects of the pilchard fishing industry. The following conclusions must thus be regarded as tentative.

Indications of an increase in the anchovy population as obtained from blanket-net haul results, are also borne out by successful commercial exploitation of this species. Large shoals have also been reported off Lüderitz, South West Africa. Increased and sustained pressure on the pilchard will only cause further disruption of the balance between the two species. A practical approach might, therefore, be to relieve pressure on the pilchard shoals by diverting some of the fishing effort to anchovy. That this is already being done by the industry is an indication of its sound planning for the future.

Fishing effort judged in terms of boat hold capacity increased almost 250 per cent since 1950 and is liable to increase even further in the foreseeable future. In Cape waters there is no clear-cut relation between landings and fishing effort and the total catch seems to have been governed mainly by the availability of pilchards. The present fishing fleet presents a formidable fishing effort which can account for a high toll of the pilchard stock. *Any further increase in overall hold capacity seems ill-advised at this stage because catches are seemingly dropping in spite of increased effort.* Assuming this is not due to natural fluctuations, the productivity of the population in inshore waters presently being fished, does not seem to be able to maintain present high catch levels.

The most outstanding feature of the size composition of the catch during the period reviewed is the dramatic change to smaller fish from 1958 onwards. One result of this phenomenon is that whereas the 1963 catch was $4\frac{1}{2}$ times that of 1950, the number of individuals caught was eight times as high. The initial predominance of younger fish can on account of the higher landings that followed, undoubtedly be interpreted as the result of excellent recruitment. Although small fish still predominate in the catches of recent years, the low spawning intensity and low yield of juveniles in blanket net catches indicate a reduced adult population and poor recruitment. The recent high frequency of small fish should thus rather be considered as due to the depletion of the adult stock.

The author is not pessimistic about the immediate future of the pilchard fishing industry. It is, nevertheless, wise to pay heed to some of the warning signs. Moreover, it should be appreciated that the tendencies exhibited more recently may be part of a natural cycle connected with environmental factors. The high temperatures during 1964 were accompanied by considerably lower catches than in previous years. Likewise the autumn catch (which normally gives a good reflection of the expected yield) during the current season has been rather moderate and it is unlikely that the total landings

will exceed 300,000 tons. Even if during the remainder of the season catches equivalent to the record landings of the corresponding months of previous years are made, the most optimistic forecast is 330,000 tons. However, this is highly improbable in view of the current tendencies; a figure of 260,000—280,000 seems a more likely estimate.

In fisheries conservation policy one perpetually has to balance the requirements of industry against the potential of the exploited resources. Unduly strict control measures have a stifling effect while unlimited relaxation can do permanent damage. Economic considerations such as a shortage of marine products and the commensurate attractive prices always warrant sympathetic consideration, but should be gauged in perspective. This has been achieved in the past by close co-operation in the protection of the resources between the industry and the authorities responsible for its regulation. It is not advisable to take risks and the approach should always be a conservative one as it affects the future of a multi-million Rand industry.